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Demonstration of the Application of Composite Load Spectra (CLS) and Probabilistic Structural Analysis (PSAM) Codes to SSME Heat Exchanger Turnaround Vane

Kadambi R. Rajagopal, Amitabha DebChaudhury, and George Orient
Rocketdyne Propulsion and Power, Canoga Park, California

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Table of Contents

Description	Page
1. Abstract	5
2. Objectives	5
3. Hardware Background	5
4. Dynamic Analysis of Components Subjected to Random Pressure Loads (Past Practices)	7
5. Air Flow test Background and Results	9
6. Description of General Distance Dependent Correlation Model With Phase Shift	13
7. Validation Problems	17
8. Computational issues in Implementing Frequency Dependent Correlation Model for the Analysis of HEX Turn Around Vane	21
9. Brief Description of the NESSUS Code	23
10. Brief Description of Composite Load Spectra Code	24
11. The Fatigue Damage Computation Module	26
12. Assembly of NESSUS, CLS and Fatigue codes and the Computational Results for Base Line Case	28
13. Probabilistic Analysis of the Base Line Case	33
14. Deterministic and Probabilistic Analysis of Redesign	36
15. Operational and Test Experience of Redesigned Vane	37
16. Summary and Conclusions	38
17. References	39
18. Appendix A - NESSUS Deterministic Annotated Finite Element Analysis Deck or the Base Line Case	41
19. Appendix B - NESSUS/PFEM Annotated Input Deck for the Base Line Case	123
20. Appendix C - CLS - NESSUS Interface Routines Called From UPSHRO	147
21. Appendix D - NESSUS Changed Routines	161
22. Appendix E - Fatigue Damage Computation Module	243
23 Appendix F- The CLS Influence Coefficient Database For Rocketdyne and ATD Environments	267
24. Appendix G - NESSUS/FEM Input Deck for Redesign Case	273

1.0 Abstract:

This report describes a probabilistic structural analysis performed to determine the probabilistic structural response under fluctuating random pressure loads for the Space Shuttle Main Engine (SSME) turnaround vane. It uses a newly developed frequency and distance dependent correlation model that has features to model the decay phenomena along the flow and across the flow with the capability to introduce a phase delay. The analytical results are compared using two computer codes SAFER (Spectral Analysis of Finite Element Responses) and NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) and with experimentally observed strain gage data.

The computer code NESSUS with an interface to a sub set of Composite Load Spectra (CLS) code is used for the probabilistic analysis. A Fatigue code was used to calculate fatigue damage due to the random pressure excitation. The random variables modeled include engine system primitive variables that influence the operating conditions, convection velocity coefficient, stress concentration factor, structural damping, and thickness of the inner and outer vanes. The need for an appropriate correlation model in addition to magnitude of the PSD is emphasized. The study demonstrates that correlation characteristics even under random pressure loads are capable of causing resonance like effects for some modes. The study identifies the important variables that contribute to structural alternate stress response and drive the fatigue damage for the new design. Since the alternate stress for the new redesign is less than the endurance limit for the material, the damage due high cycle fatigue is negligible.

2.0 Objectives:

The objective of the program was to demonstrate the Probabilistic Analysis and Design Methodology approach to an aerospace hardware. The methodology was used to analyze the baseline design of the SSME heat exchanger turnaround vane that experienced cracking when used in conjunction with Alternate Turbopump Design (ATD) high-pressure oxidizer turbo-pump. After the base lining of the models and methodology for the base line design, the methodology was used to analyze the new design configuration. The study identified the maximum fatigue damage locations and sensitivity of the designs to identified random variables.

3.0 Hardware Background:

The heat exchanger turning vane is part of the SSME hot gas manifold assembly (Figure 1). Its purpose is to facilitate the 180 degree turn of the High Pressure Oxidizer Turbo Pump (HPOTP) turbine exhaust hot gas that then flows over the heat exchanger (HEX) tubes before the gas discharges in to the transfer ducts of the hot gas manifold. The HEX turning vanes (Inconel 625 material) which had no history of failures with the Rocketdyne HPOTP during the SSME development and operational history, started developing cracks at approximately 1000 seconds of hot fire operation with the ATD turbine discharge flow environment (referred to as the baseline case through out this report). The solution involved the near term fix and a new re-design fix. The near term

fix involved "cut-back" (Figure 2) and in some cases a hybrid cut back and bolted design fix. The redesign solution involved thickening of the vane (Figure 3). This (Figure 3) is referred to as redesign configuration through out this report. The material for the new design is Nickel base casting Alloy 625. The "cut-back" solution showed substantial life improvements and had seen over 55,000 seconds of operation with no evidence of cracking on one engine. The fleet leader engine with the new redesign has seen over 55,000 seconds and 110 starts with no distress. There are 11 engines in service with the new redesigned vane to date.

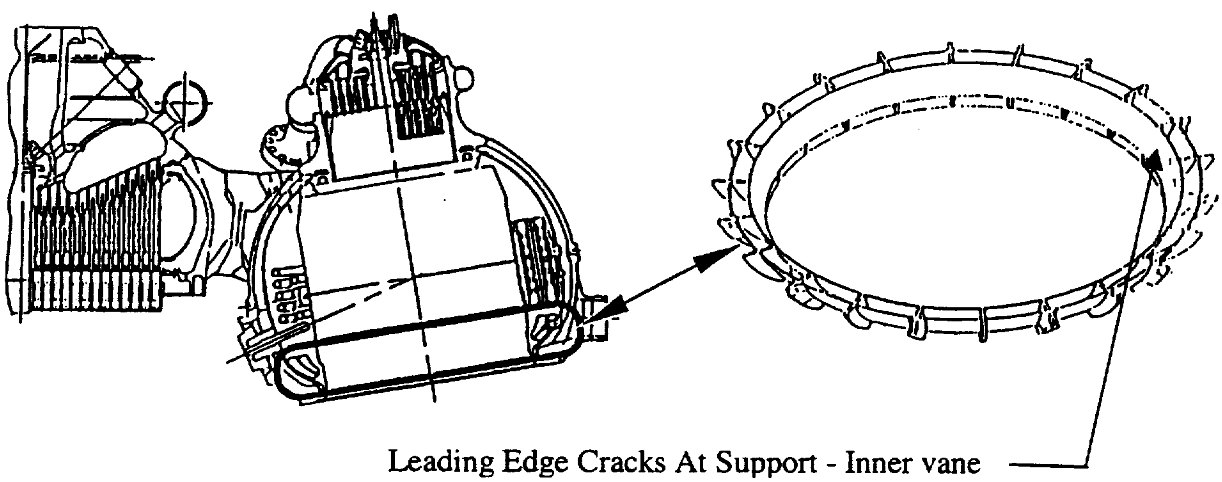


Figure 1. The Heat Exchanger Turning Vane in the SSME Hot Gas Manifold

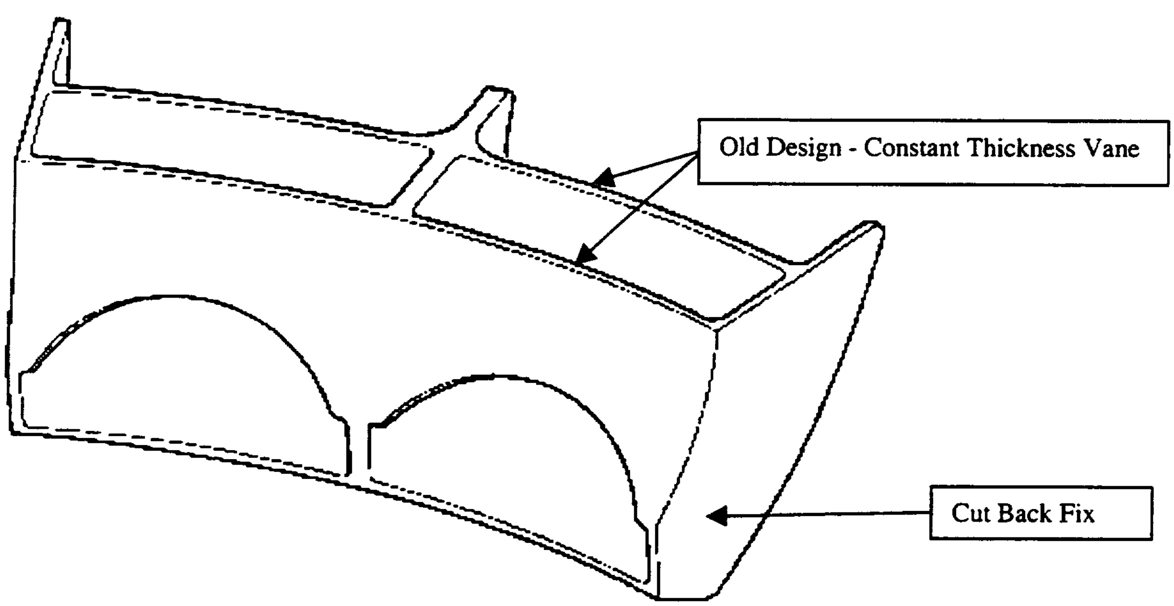


Figure 2. Cut Back Modification as a Near Term Fix

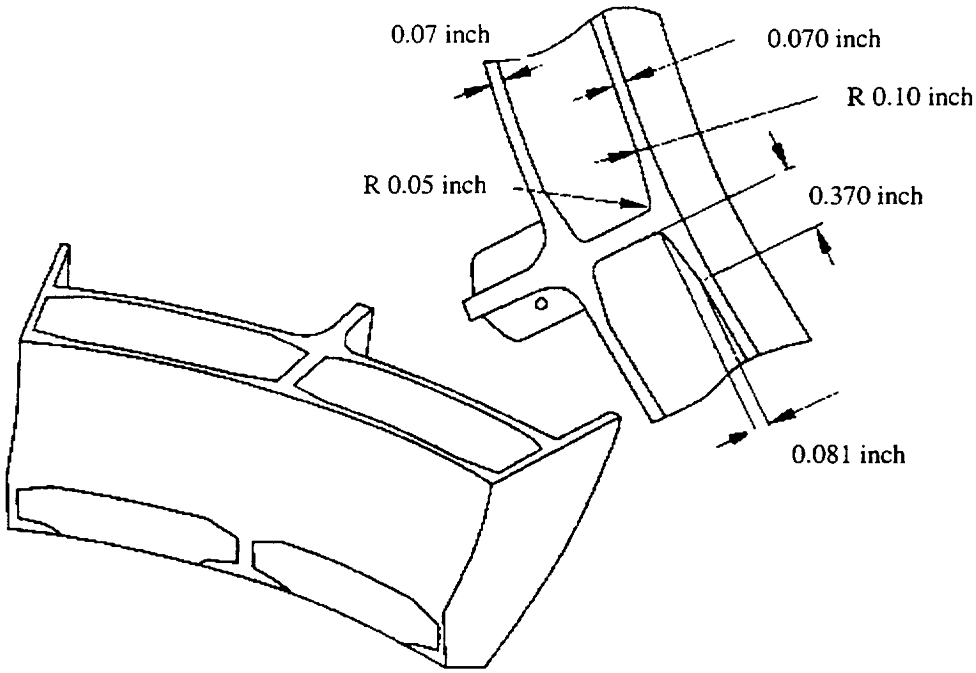


Figure 3. New Design for the Hex Turnaround Vane

4. 0 Dynamic Analysis of Components Subjected Random Pressure Loads (Past Practices):

Historically, an accurate dynamic structural analysis for rocket propulsion components under random pressure loads has been difficult. Some of the reasons for the difficulty are

- difficulty in instrumentation and obtaining random pressure load definitions from actual engine tests
- the limited dynamic pressure sensor measurements on the engine tests are not time accurate to form a basis for any meaningful correlation information derivation.
- absence of predictive analytical internal fluid flow models (computer codes) for determining dynamic fluid pressures for the frequency ranges of interest (0-5000 Hz)
- inaccurate dynamic load correlation models
- the lack of capability in the structural analysis codes to use these advanced features of defining complex dynamic loading environment
- the computational burden imposed by the analysis when these procedures need to be applied to realistic production finite element models.

The above mentioned factors lead to the use of a simplistic distance dependant decay correlation model. For distant dependent decay correlation model, the correlation Coefficient is approximated as (Figure 4.0)

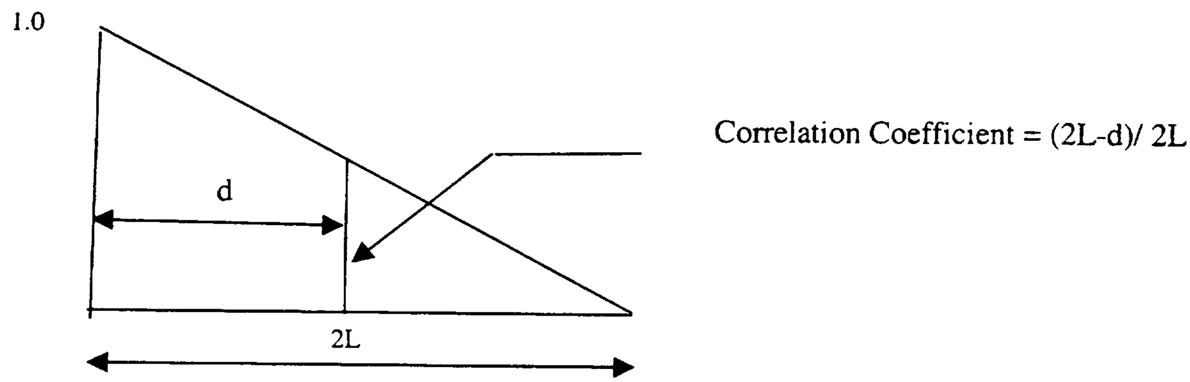


Figure 4.0 Distant Dependant Correlation Model

The above model can be generalized further to multi-linear correlation model (Figure 5.0.) This model is implemented on NESSUS (reference 1) and other commercially available codes such as Stardyne and in Rocketdyne developed in-house code Spectral Analysis of Finite Element Responses (SAFER) (reference 2). SAFER is mentioned here as it is used to compare and verify results with the NESSUS implementation.

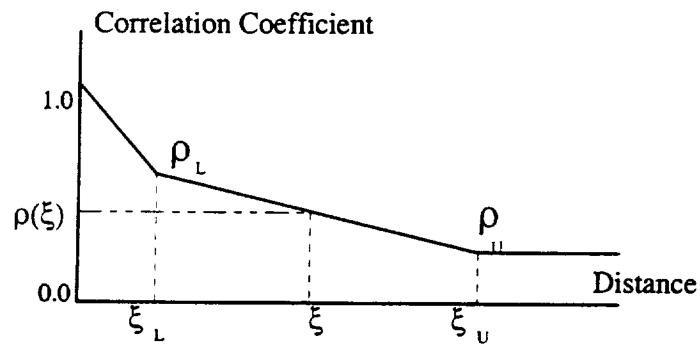


Figure 5.0 Multi-linear Distance Dependant Correlation Model.

The correlation coefficient between fluctuating pressure excitation at two points in the structure separated by a distance ξ is given by:

$$\rho(\xi,x,t)=\rho(\xi)=\frac{E[P(x,t).P(x+\xi,t)]}{\sqrt{E[P^2(x,t)]E[P^2(x+\xi,t)]}}=\begin{cases}1-(1-\rho_L)*\xi/\rho_U & \text{if } 0\le\xi\le\xi_L\\ \rho_L-(\xi-\xi_L)*(\rho_L-\rho_U)/(\xi_U-\xi_L) & \text{if } \xi_L\le\xi\le\xi_U\\ \rho_U & \text{if } \xi\ge\xi_U\end{cases} \quad (1)$$

where the parameters $\xi_L, \rho_L, \xi_U, \rho_U$ are illustrated in Figure 5.0. The distance between two points ξ in space can be computed as the absolute distance or relative to a focal point or along a prescribed directional vector.

The intensity of pressure load can have a spatial distribution. The pressure correlation field, however, is assumed to be homogeneous with respect to time (stationary) and space. For $\xi_L = 0$, $\rho_L = 1$ & $\rho_U = 0$; Correlation Length is defined as $= \xi_U / 2$.

Since there is significant uncertainty in correlation length estimation, several analyses are usually run with different correlation lengths to match the experimentally observed strain gage data. For the class of problems with internal flow discussed in this report, this approach usually results in matching the experimentally observed data at a select point but matching the analytical results over a field has not been successful.

5.0 Air Flow Test background and Results:

The airflow test was conducted as part of the SSME project effort for the Heat Exchanger turning vane with several configurations under consideration at that time. This contract effort utilized the available test information for the purposes of analysis reported here. The air flow tests on plexi-glass scale models were the only source for estimating the dynamic pressure field near the turnaround vane as it was nearly impossible to locate any dynamic pressure transducers in the up stream vicinity of the HEX vane in an actual engine

The development of the correlation model used in this study is the result of the combination of airflow data and direct measurements of structural response in the form of strain gage measurements from actual engine tests. The air flow test results indicated that the R.M.S random pressure intensity under the Alternate Turbo Pump Design (ATD) increased by a factor of approximately seven or more, while the strain gage response showed only a factor of two increase over the Rocketdyne pump environment.

Table 1 Comparison of RMS Power Levels between Different Configurations.

Configuration	Fluctuating Pressure (PSI) 0 1 2 3 4 5 6 7 8 9 10
Rocketdvne Baseline	
ATD Baseline	

This difference between the increase in loading (ATD Vs Rocketdyne Baseline) and less than corresponding increase in response lead to a more detailed analysis of the airflow data. However, the data analysis as described below showed a strong correlation between the pressure measurements of the microphones located at the leading, trailing edge and mid stream of the vanes. The data also pointed to the way of modeling phasing to represent the loading accurately. Thus the new model implements these features that

were observed in the air flow test data. The implementation was verified through NESSUS and Safer computer codes.

The air flow test set up with locations of the microphones are shown in Figure 7.0 The suction side microphones are labeled from 1 to 4 starting with the leading edge and the pressure side microphones are labeled 5-8 starting with the leading edge. The differential pressure is computed as the difference in corresponding pairs such as 1-5.

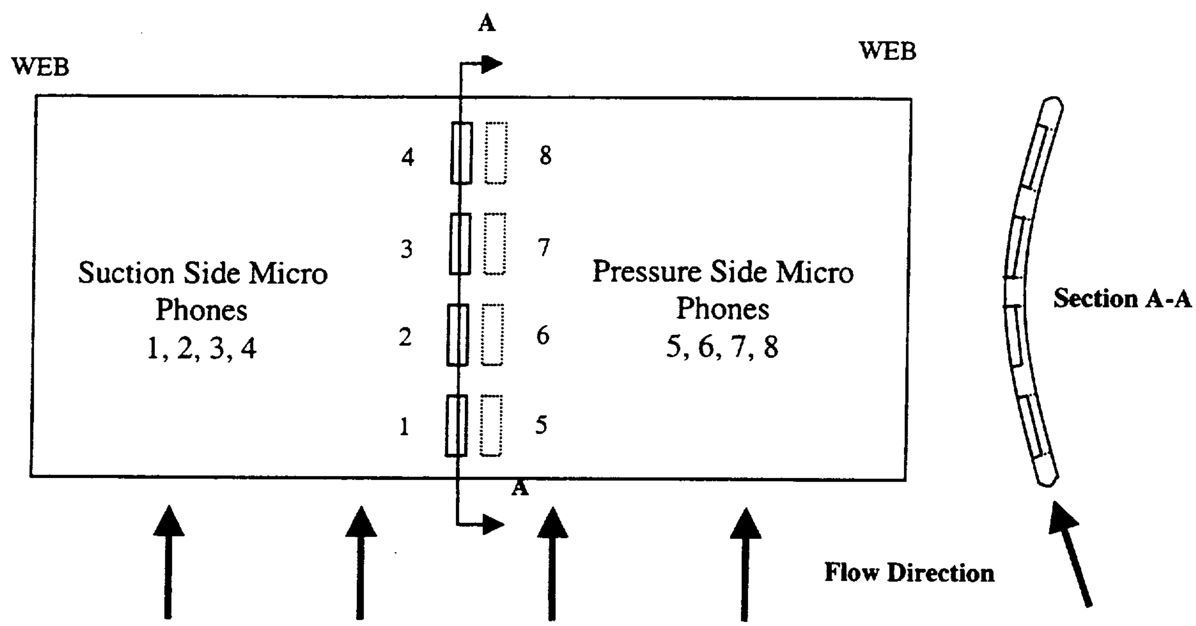


Figure 7. Microphone Locations on the Vane in the Airflow Test Rig

The cross correlation function is defined as

$$\rho_{xy}(\tau)=E[x(t)\cdot y(t+\tau)] \qquad (2)$$

Analysis of data between the measurements 2-3 (Figure 8) and 3-4 (Figure 9) yielded similar results. Notable features are the shape of the correlation function, similarity of correlation function between similar pairs 2-3 and 3-4 and the decay in correlation function magnitude between sensors located farther apart such as between 2-4 (Figure 10) and 1-4 (Figure 11).

It must be noted in a conventional dynamic analysis the correlation function data is not utilized. Instead, the correlation coefficient, which is the intercept at the origin, is utilized. Consequently a simple distance dependent correlation model can lead to erroneous structural response results. In the case of HEX turn around vane analysis correlation coefficient based (simple distance dependant model) missed the stress response b several orders of magnitude.

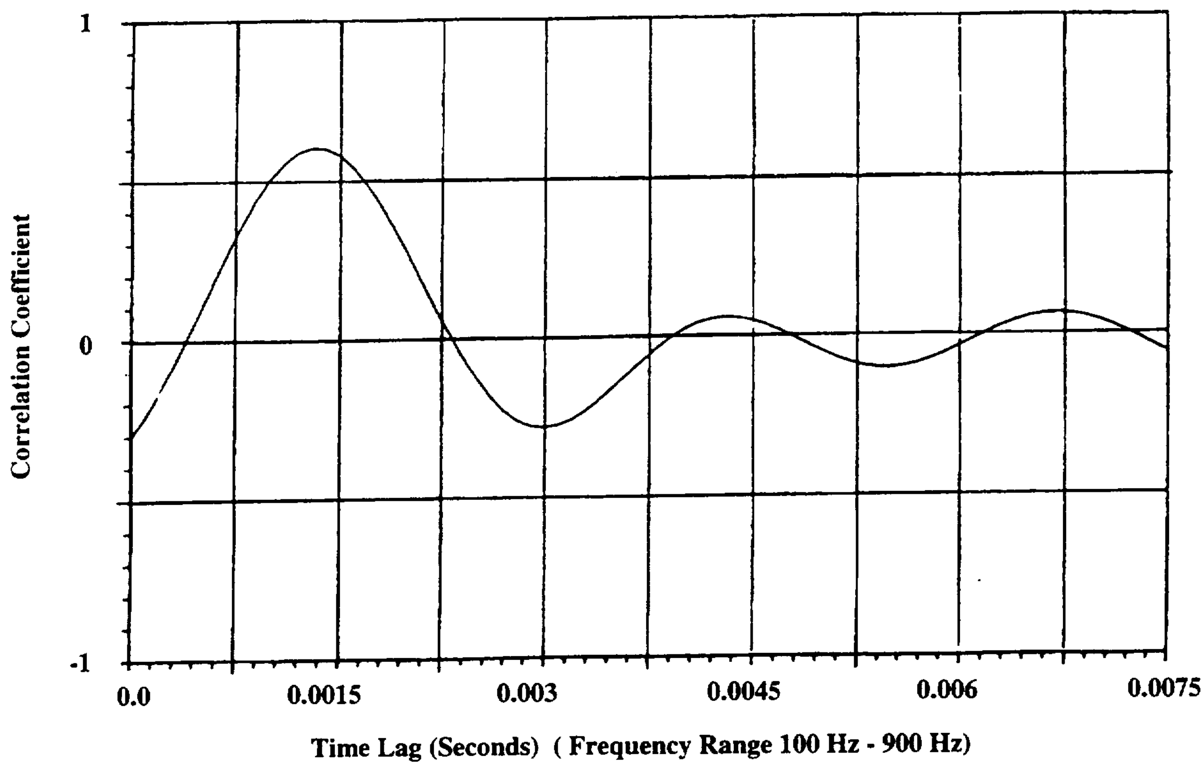


Figure 8. Correlation Function Between Pressure Sensor Locations 2-3

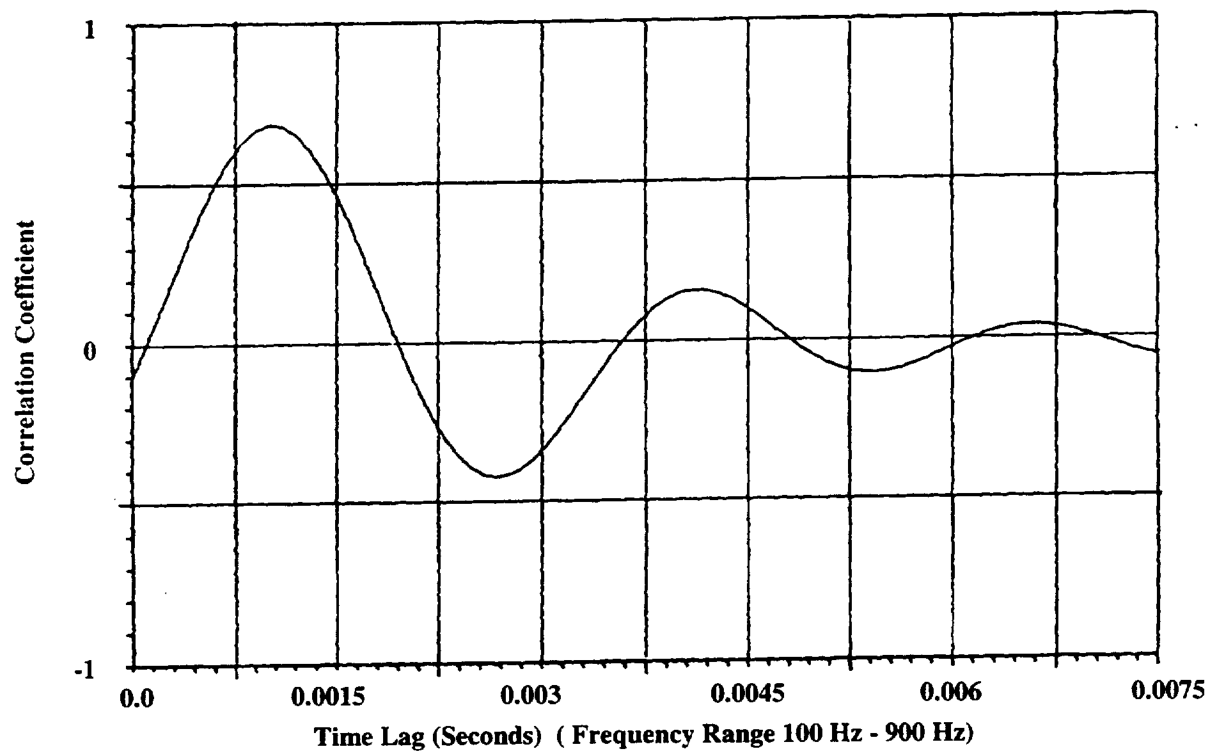


Figure 9 Correlation Function between Pressure Sensor Locations 3-4

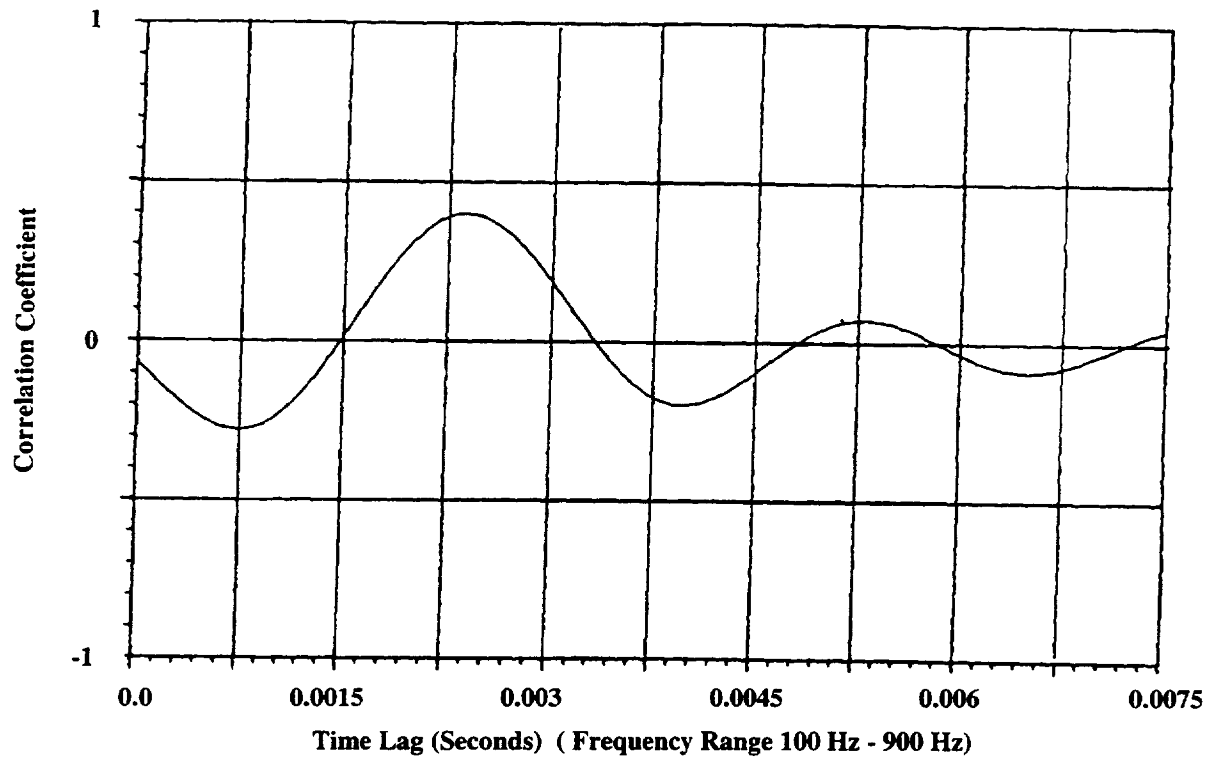


Figure 10. Correlation Function between the Pressure sensors 2-4

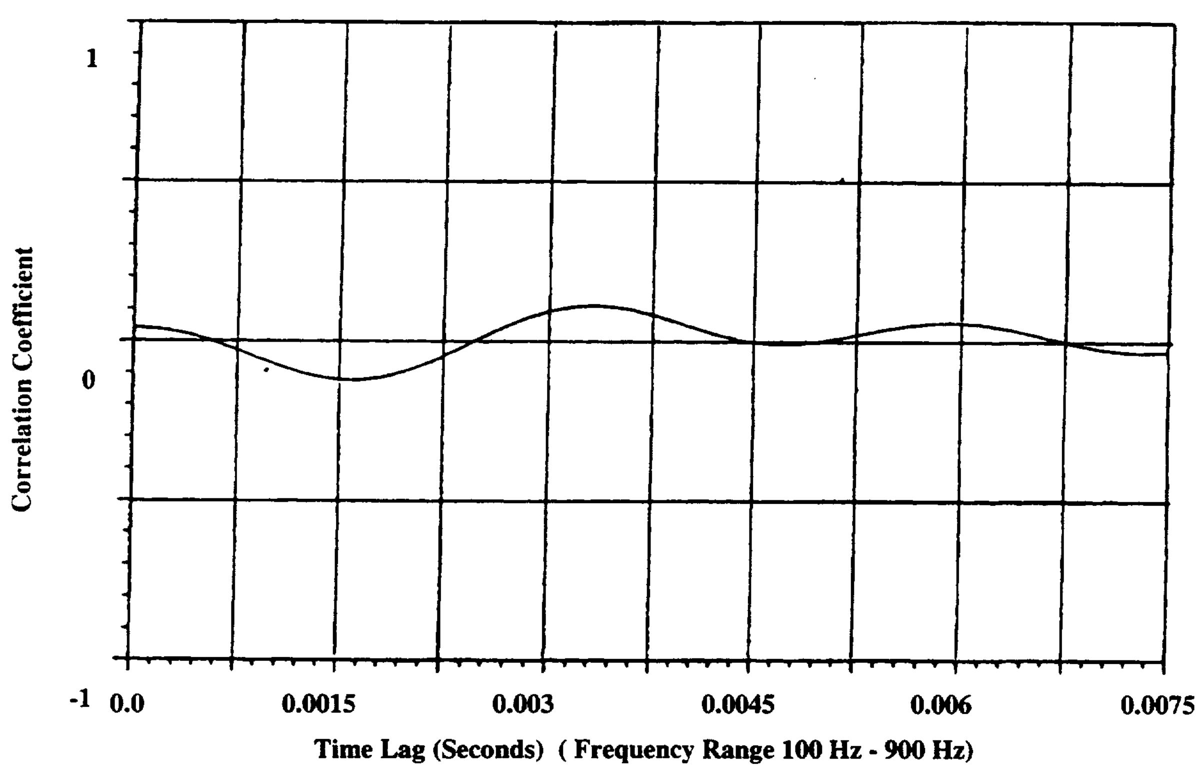


Figure 11. Correlation Function between the Pressure sensors 1-4

Further analysis of the airflow data indicated that the decay in correlation was not a strong function of frequency and hence the correlation model ignored that term.

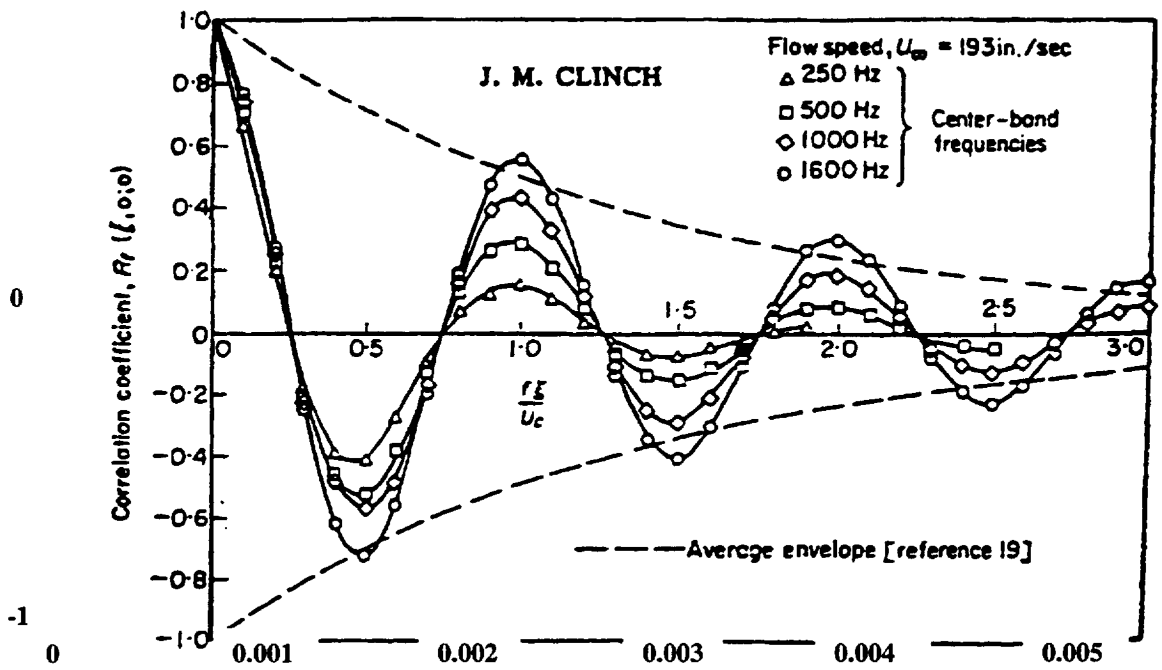


Figure 12. Test Results from J. M.Clinch (Reference 3)

The data supported the hypothesis of strong correlation with phase difference and distance dependant decay. The above results are consistent with the literature as reported by J. M. Clinch (reference 3) and shown Figure 12.

6.0 Description of a General Distance and Frequency Dependent Correlation Model with Phase Shift

Let ξ(t) and η(t) be two random processes representing the fluctuating random pressure at two points A and B in space at a given time t (Figure 13). Furthermore it is assumed that the point B is downstream relative to the point A.

The cross correlation function and its Fourier transform pair cross spectral density function between the two processes ξ(t) and η(t) are defined as:

$$R_{\xi\eta}(\tau) = E[\xi(t).\eta(t+\tau)] = \int_{-\infty}^{+\infty} S_{\xi\eta}(\Omega).e^{i\Omega\tau}d\Omega \tag{3}$$

$$S_{\xi\eta}(\tau) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} R_{\xi\eta}(\tau).e^{-i\Omega\tau}d\tau \tag{4}$$

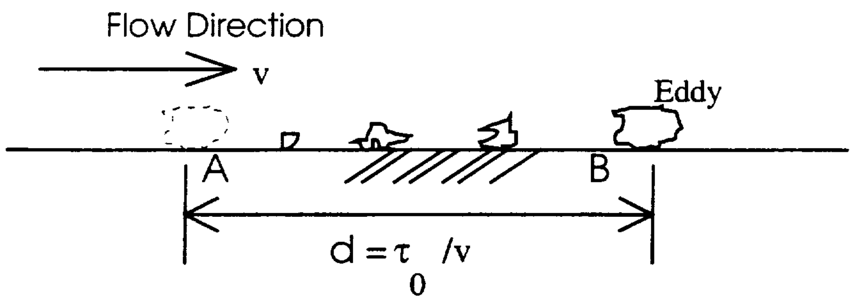


Figure 13. Two Random Processes A and B Separated by Distance Modeled by Correlation Model

The fluctuating pressure $\eta(t)$ at some downstream point B can be assumed to be composed partly of noise due to the same eddies passing through the upstream point A that decays with distance and phase shifted due to the time delay. The remaining part of the excitation can be assumed to be caused by some new eddies formed after the fluid leaves the point A. This part can be assumed to be uncorrected to the previous part. Mathematically the process $\eta(t)$ can be written in terms the process $\xi(t)$ as:

$$\eta(t) = \alpha.\xi(t - \tau_0) + \varepsilon(t) \tag{5}$$

Where:

α - the decay parameter

$\xi(t)$

- fluctuating pressure at A at time t

$\eta(t)$

- fluctuating pressure at B at time t

τ_0 = d / v - time delay = time taken by an eddy to move from point A to point B

d - the separation distance (distance between point A & B)

v - the velocity of propagation (convection velocity)

$\varepsilon(t)$ - a random process independent of $\xi(t)$

Then it can be shown that the cross correlation function between the two different processes ξ(t) and η(t) can be expressed in terms of the auto correlation function of the process ξ(t):

$$R_{\xi\eta}(\tau) = \alpha . R_{\xi\xi}(\tau - \tau_0) \tag{6}$$

Corresponding cross-spectral density function can then be written as:

$$S_{\xi\eta}(\Omega) = \alpha . S_{\xi\xi}(\Omega) . e^{-i\Omega\tau_0} \tag{7}$$

The above model can be graphically represented in Figure 14:

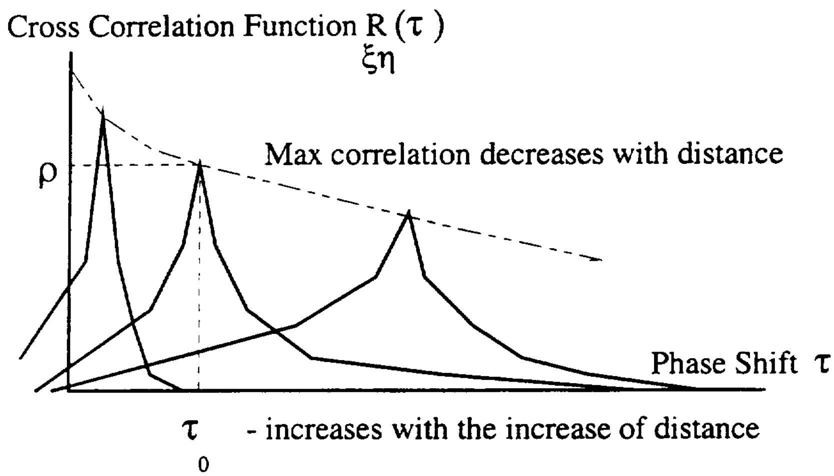


Figure 14. The Cross Correlation Function

A simple schematic representation of the features of the correlation model's decay part is illustrated in Figure 15. The schematic illustrates the correlation model characteristics that the decay rate across the flow is much greater than the decay rate along the flow. Since the airflow measurements did not provide the decay rate across the flow, it was assumed to be a ratio parameter of 6 as suggested by Clinch (reference 3). As evidenced by the airflow test results, the decay as a function of frequency was not considered significant in this case and hence was not modeled. The frequency only affects the phase difference as seen in Figure 16. Some of the characteristics of this model are different frequency bands will have different phase distribution amplifying different modes. Also for a given frequency band, the phasing changes with the convection velocity.

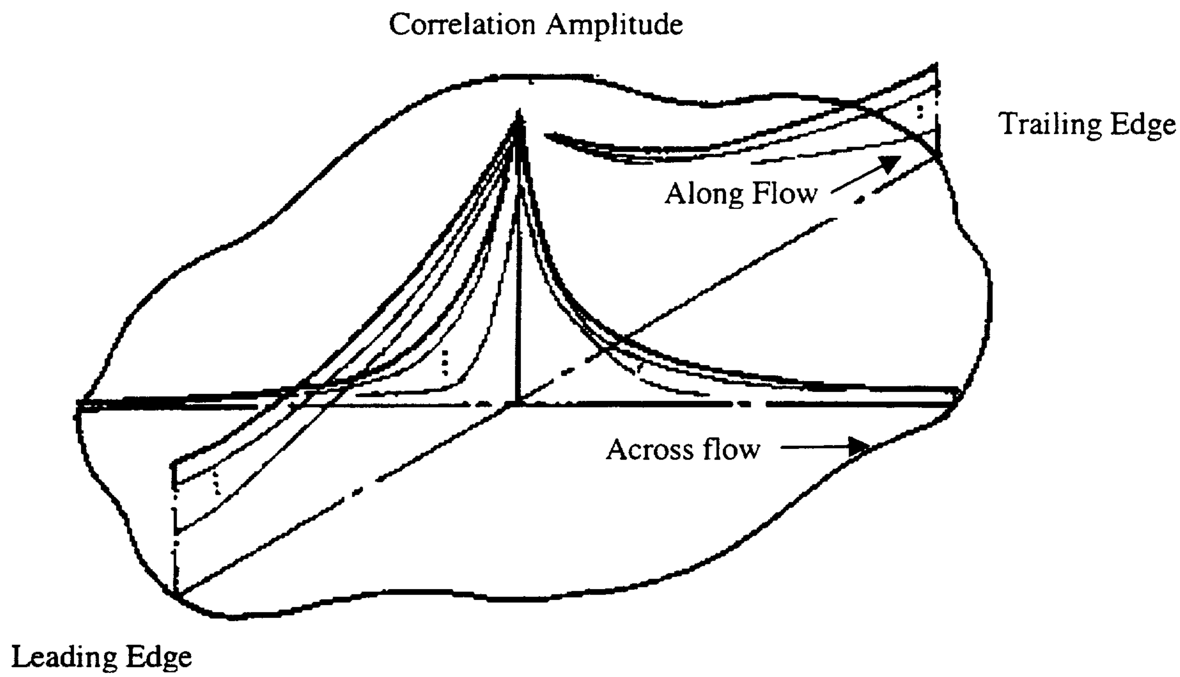


Figure 15. Schematic Representation Of Across the Flow and Along the Flow Decay Ratio.

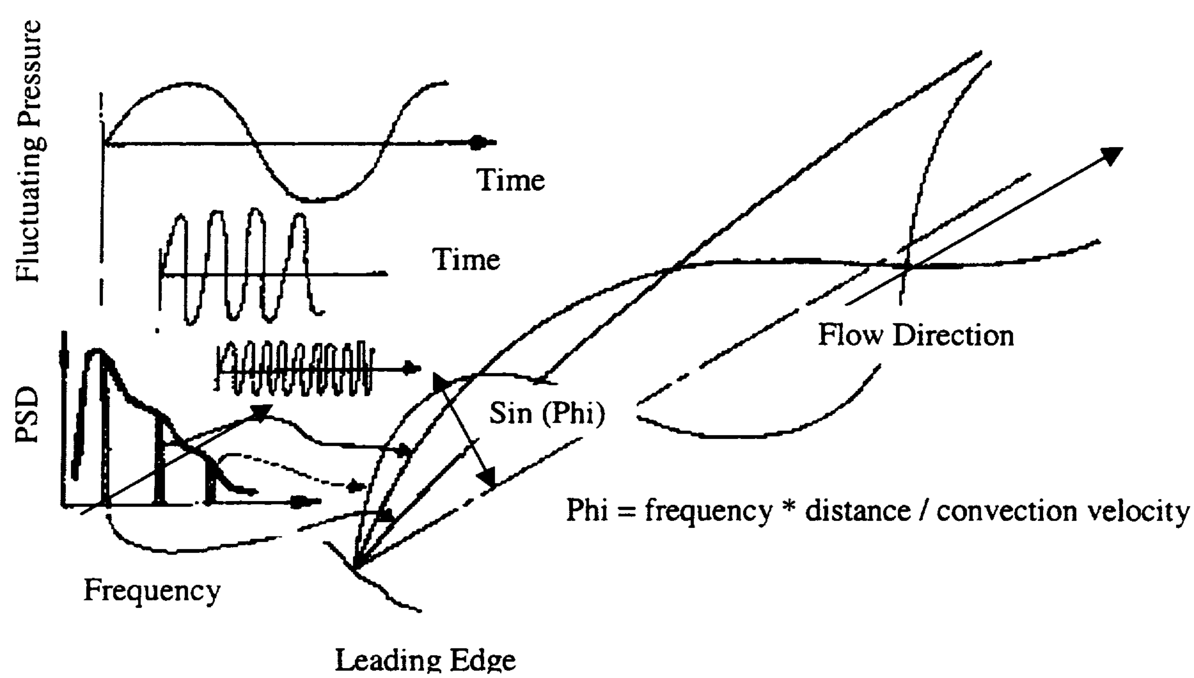


Figure 16. Phasing modeled as a function of Frequency

The cross-spectral density function for two points k & l in space will be defined as:

$$S_{kl}(\Omega) = S_0 \left\{ e^{-\lambda_c \Omega^{m_c} \left| d_c^{n_c} \right|} \right\}_{kl} \left\{ e^{-\lambda_r \Omega^{m_r} \left| d_r / v \right|^{n_c}} \right\}_{kl} \left\{ e^{-i\Omega d_r / v} \right\}_{kl}$$

$$S_{lk}(\Omega) = S_{kl}^{*}(\Omega) \tag{8}$$

Where:

d_c - distance between k & l across the direction of propagation

d_r - distance between k & l along the direction of propagation

v - velocity of propagation

λ_c, m_c, n_c - decay parameters across the direction of propagation

λ_r, m_r, n_r - decay parameters along the direction of propagation

$|\,.\,|$ – absolute value of

7.0 Validation Problems

Validation Problem 1:

The purpose of the validation problems is to verify the results produced by finite element implementation and closed form solutions. A two degree of freedom spring mass system was chosen for this purpose. The problem was analyzed for a narrow band and a wide band white noise excitation spectrum. The closed form solution was possible due to the simplistic nature of the verification problem. The finite element results are compared between three different finite element codes.

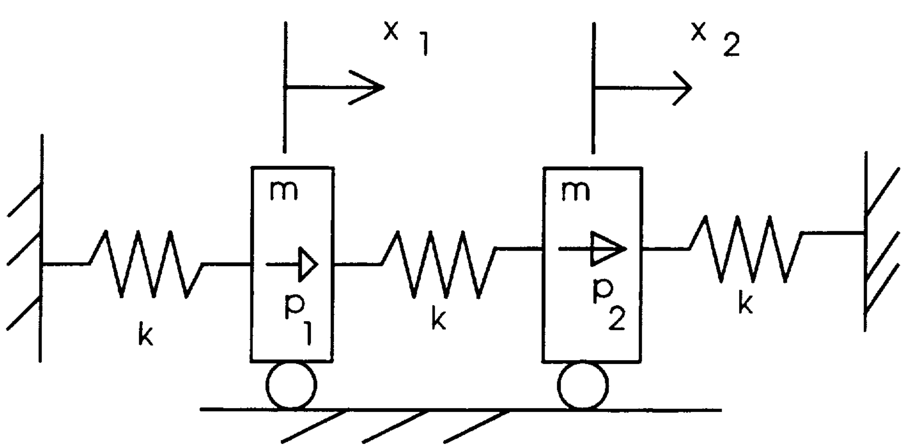


Figure 17. Two Degree of Freedom Validation problem

The equation of motion is defined as $\begin{bmatrix} m & 0 \\ 0 & m \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{Bmatrix} + \begin{bmatrix} 2k & k \\ -k & 2k \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{Bmatrix} p_1 \\ p_2 \end{Bmatrix}$ (9)

spring stiffness $k = AE / L = 1.0 * 25.5E6 / 0.5 = 51.E6$

lumped mass m = 4.0

Damping ratios for the 2 modes are assumed to be 0.05 for all the subsequent analysis.

The natural frequencies of the system are shown in Table 2 and the dynamic response results are shown in Table 3 for narrow banded excitation and in Table 4 for wide banded excitation.

Table 2. Natural Frequency Comparison - Analytical and Finite Element Models

Natural Frequencies	Analytical	NESSUS	STARDYNE
ω_1	3570.7142	3570.57	3570.7142
ω_2	6184.6584	6184.51	6184.6584

Table 3. Comparison of Responses for Narrow Banded Excitation - Analytical and Finite Element Models

Velocity	Corresp Phase	Analytical RMS Displ. (x 10.0e6 in)		NESSUS RMS Displ. (x 10.0e6 in)		SAFER RMS Displ. (x 10.0e6 in)	
In/sec	radians	x1	x2	x1	X2	x1	x2
3183.0992	$\pi/4$	0.486657	0.380539	0.48086	0.37599	0.4866569	0.3805387
1591.5496	$\pi/2$	0.493941	0.337393	0.4881	0.3334	0.4939406	0.3373928
795.7748	π	0.402558	0.402558	0.39784	0.39784	0.4025578	0.4025578
397.8874	2π	0.442446	0.442446	0.43716	0.43716	0.4424459	0.4424459

$$S_{pp}(\Omega) = \begin{cases} 480000 \; if \; 5000.0 \le \Omega \le 5000.001 \\ 0 \quad otherwise \end{cases}$$

$$m_c = m_r = 0 \quad \& \quad n_c = n_r = 1$$

$$\rho_r = 1.0 \quad at \quad d_r = 2.0'' \quad \& \quad \Omega_r = 1500. \quad Hz$$

$$\rho_c = 1.0 \quad at \quad d_c = 2.0'' \quad \& \quad \Omega_c = 1500. \quad Hz$$

Table 4 Comparison of Responses for Wide band Excitation - Analytical and Finite Element Models

Max Correlation Coefficient		NESSUS RMS Displacements (x 10.0 e 6 in)		SAFER RMS Displacements (x 10.0 e6 in)	
ρ_r	ρ_c	X1	x2	x1	x2
1.0	1.0	1.035712	0.922199	1.035735	0.922220
0.1	0.03	0.954987	0.887147	0.955015	0.887169
0.01	0.001	0.906444	0.8668102	0.906470	0.866836

$$m_c = m_r = 0; n_c = n_r = 1 \& Velocity = 1591.5496 in / \sec$$

$$d_r = 2.0'' \& \Omega_r = 1500. Hz \quad d_c = 1.0'' \quad \& \quad \Omega_c = 1500. \quad Hz$$

Validation Problem 2:

The second chosen verification problem is the response of a simply supported rectangular plate subjected to banded random (sine) pressure excitation. The problem is more representative of the Hex turnaround vane, which is two dimensional, modeled with shell finite elements, and is subjected to similar flow conditions with across and along the flow correlation characteristics. The validation problem demonstrates the sensitivity of the structural dynamic response to flow velocity (that controls the phasing). For the same PSD magnitudes, entirely different structural responses are obtained based on the flow velocity, which control the phasing. The details of the model along with its natural frequencies are shown in Figure 18.

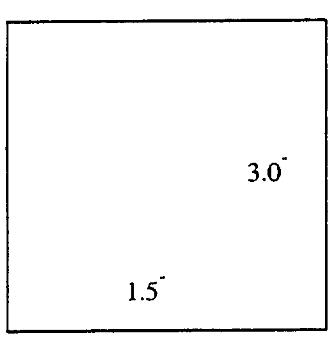


Plate Properties

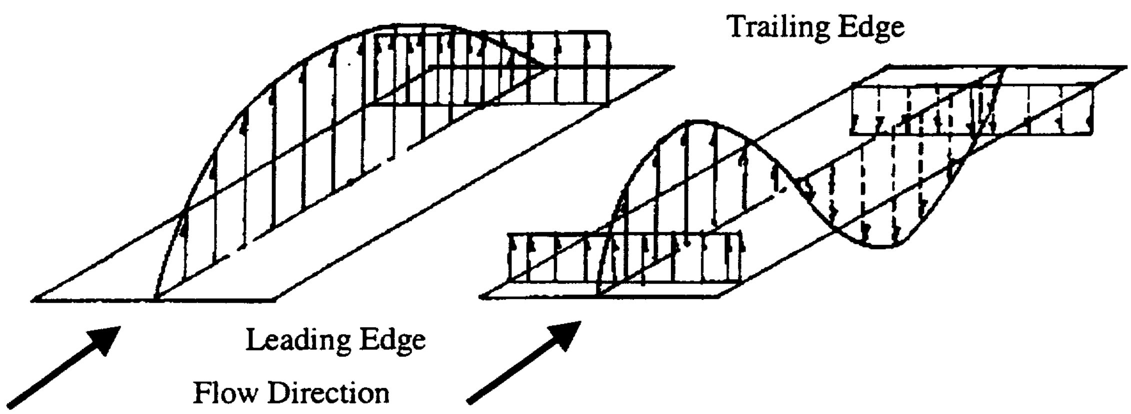
Thickness: 0.05"
Elastic Modulus: 30.0E06
Boundary Conditions: SS on all four sides
Mesh: 100 Quad Elements
Pressure: 4psi RMS Uniform

Figure 18. Rectangular Plate Verification Problem

Table 4
Natural Frequencies for Verification Problem 2

Code	Frequency 1	Frequency 2	Frequency 3	Frequency 4
NESSUS	2418.02	3920.73	6672.10	8472.73
STARDYNE	2373.682	3754.728	6098.041	8031.795

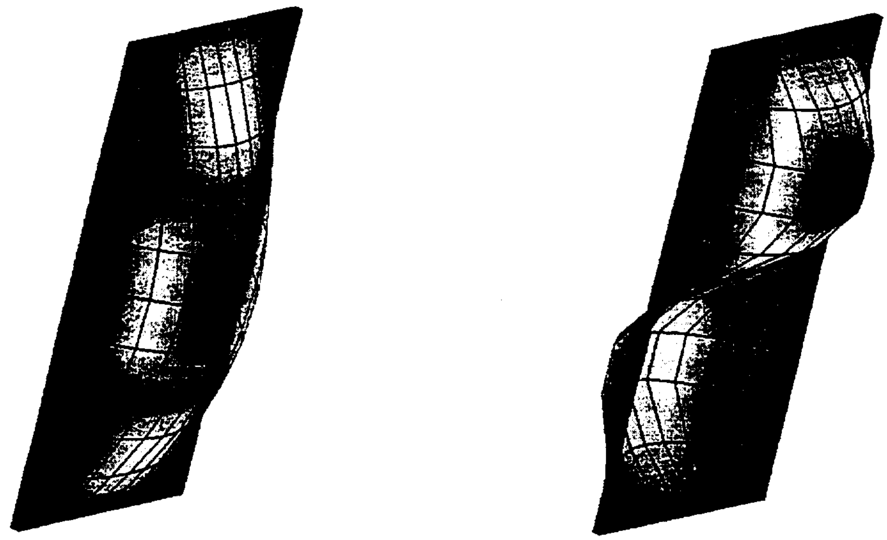
The difference in the computed natural frequencies between Stardyne and Nessus can be attributed to different finite element formulations. The convection flow velocity is adjusted such that the phasing is 180 degrees or 360 degrees as illustrated in Figure 19.



a: Phase Lag 180 Degrees b. Phase Lag 360 Degrees

Figure 19. Tuning of Convection Velocity to Produce Spatial Distribution of Phase Lag

A fringe plot of the computed RMS surface stresses in the flow direction for two velocities is show in Figure 20.



a. Flow velocity 4500inch/sec b. Flow velocity 9000 inch/sec

Figure 20. Effect of Flow Velocity on Surface Stresses in the Y- direction. NBRP at 300 Hz (Between 1st and Second Mode)

8.0 Computational Issues in Implementing Frequency Dependant Correlation Model for the Analysis of HEX Turnaround Vane:

The frequency and distance dependant correlation model increases the computational burden several folds over the conventional distance dependant correlation model as approximated by the following expression.

Machine CPU Time = K * (Number of Modes)^2 * (Number of Excitation Points)^2 * (Number of Frequency Bins)^2

where K is a machine constant.

The Hex turnaround vane is a shell structure and the excited modes are usually the shell modes, which are in the higher frequency range. The SAFER code was used to compare the finite element results with that of NESSUS code. For the 360 degree model analyzed using SAFER computer code, the number of modes that were considered in the analysis were 150. In a random pressure excitation problem every node in the finite element model that is exposed to the gas path is excited. This can be contrasted with the random mechanical support vibration problem in which only a few support nodes are applied with excitation. Further, since the damping in the HEX turnaround vane is negligible (< 0.005%), the random vibration analysis techniques that deploy numerical integration techniques (e.g. NESSUS code), the bin width for the frequency integration has to be necessarily small. The HEX turnaround vane problem the bin width that was used to analyze was less than 2.5Hz and the PSD excitation up to 10000 HZ was considered in the analysis. It is the combination of the above factors that contribute to

significant increase in computational burden. With out the simplifying assumptions described below, it was not feasible to solve this problem in Nessus.

Several strategies were considered for a reduction in problem size. This was necessitated due to the fact the NESSUS computer code uses an in-core solution technique (for solving system equilibrium equations amounting several thousand degrees of freedom) and the available computer resources at that time were limited to 64 million words. When combined with the parameters that were outlined previously, simplification of the analysis requirements was necessary. The strategy was to consider the cyclic symmetry nature of the problem and reduce the problem size while capturing the essential physics and minimize the discretization errors and disturbances due to the proximity of the boundary condition.

Since the turbine and the turning vane are cyclic symmetric, a reasonable assumption that that loading is also cyclic symmetric can be made. Smallest segment under the cyclic symmetry condition is a two bay model (Figure 21). However, since the maximum stresses for the baseline cases were occurring over the support, in order to minimize the boundary condition proximity disturbances, a six bay model but loaded only in two bay at the center provided a compromise (Figure22). This is an approximation and if the model was analyzed using only two bays, then the total response due to all bays loaded could be obtained by root mean sum square approach. This introduces the assumption that the loading is un-correlated between the bays, which is reasonable, considering there are webs that divides each cyclic symmetric segment. Further, Only the center two bays of the model were loaded with the pressure loading and the full effect through root sum square approach. This approach was verified by using the results from the SAFER computer code using a 360-degree model. SAFER computer code results were also used to compute the factor that the two bay loaded results need to be multiplied with to obtain full 360-degree loaded condition. Since the Safer computer code did not utilize numerical integration technique to compute dynamic responses, it was feasible using Safer to perform the random pressure loading response analysis for the full 360 model with an acceptable computational burden. Many parametric studies were conducted in Safer prior to running the problem in Nessus to obtain the probabilistic response.

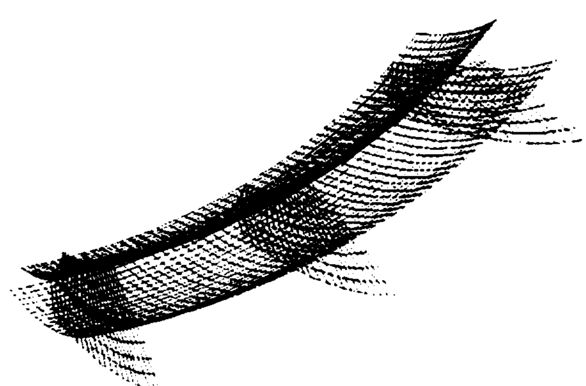


Figure 21. A Two Bay Model of the Hex Turnaround vane

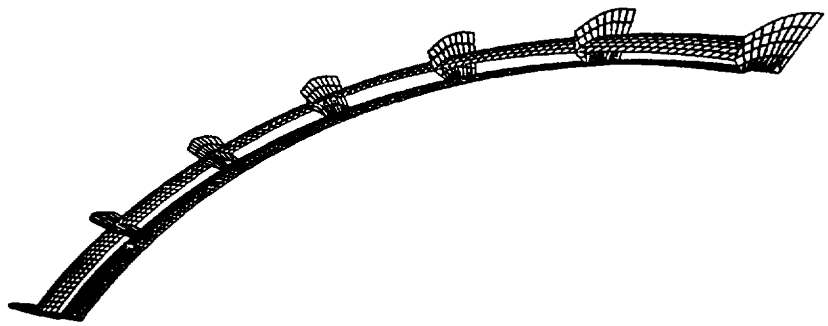


Figure 22. A Six bay Model of the HEX Turn around Vane

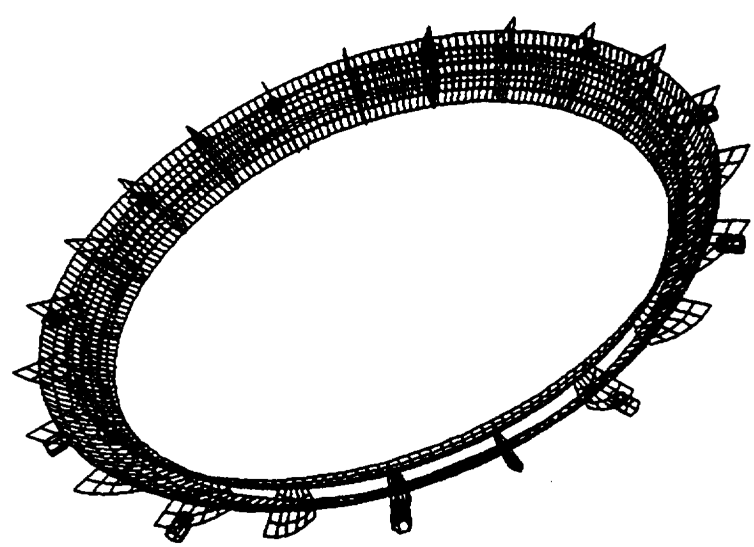


Figure 23. A 360 degree HEX Turnaround vane Model

9.0 Brief Description of the NESSUS code:

The NESSUS probabilistic structural analysis computer program combines state of the art probabilistic algorithms with general-purpose structural analysis methods to compute the probabilistic response and the reliability of engineering structures. NESSUS computer code is the result of NASA Glenn Research Center sponsored research entitled

Probabilistic Structural Analysis Methods for Space Propulsion System Components (Reference 2). Uncertainty in loading, material properties, geometry, boundary conditions and initial conditions can be simulated. The structural analysis methods include nonlinear finite element methods, boundary element methods, and user written subroutines. Several probabilistic algorithms are available such as advanced mean value method and adaptive importance sampling methods.

In this application the following features of the NESSUS computer code were utilized:

- Finite element analysis using shell elements
- Modal analysis using subspace iteration
- Random vibration analysis under random pressure loading in frequency domain using numerical integration
- User defined subroutine for use of specialized correlation model
- Probabilistic Structural Analysis using Mean value First order method and Advanced Mean Value First Order Method (Plus).
- Operations on the basic finite element results using user defined operation subroutines
- Facility in the NESUS code to link user defined codes including the CLS interface codes and Fatigue codes in the UZFUNCTION sub routine

10.0 Brief Description of the Composite Load Spectra Code:

The Composite Load Spectra (CLS) computer code is the result of NASA Glenn Research Center sponsored research program (Reference 4). It is a generic framework tool for probabilistic load Simulation for rocket propulsion engines. The Space Shuttle Main Engine (SSME) system has been used as a demonstration case for the CLS code capability.

The CLS code has many components to model the engine to engine and test to test load variations, both static and dynamic. Some of the components of the CLS load model are 1) the engine system influence coefficient model and the associated database, 2) the statistical dynamic vibration environment database, 3) the expert system and 4) vibration environment scaling system. Only the influence coefficient model and the associated database at a sub-component level have been used in the HEX turn around vane study. The CLS knowledge database was also utilized to obtain the statistical data for the engine system primitive variables. The complete description of the code and its capabilities can be found in the cited reference.

The key elements of the CLS code for this application are the influence coefficient model and a corresponding influence coefficient database. The form of the influence coefficient model is as follows:

$$\frac{\Delta Y_j}{Y_j} = \sum_i (IC)_j \frac{\Delta X_i}{X_i} \tag{10}$$

Where

X_i = independent engine system primitive variables
Y_i = dependent engine system variables
$(IC)_{ij}$ = are the influence coefficients

The influence coefficients are obtained for each engine configuration from a power balance model. The influence coefficients are defined as coefficients of an approximate 3rd order polynomial fitted through seven power levels defined as follows.

$$IC(T) = C_0 + C_1 T + C_2 T^2 + C_3 T^3 \quad (11)$$

$$Y(T) = a_0 + a_1 T + a_2 T^2 + a_3 T^3 \quad (12)$$

where T is the engine power level in unit value. Thus the influence coefficient model is linear to the independent variables at a given power level for small perturbations (typically 5%) but is nonlinear with respect to power level. The influence coefficient database was different for the Rocketdyne environment (SSME) and ATD environment (Block I, SSME). For the heat exchanger turnaround vane problem, the dependent variables of interest are

1. Turbine mass flow rate
2. Turnaround duct gas density
3. Turnaround duct flow velocity

The first two affect the PSD intensity component of the dynamic load on the vane while the velocity affects the frequency dependent part of the correlation model. The variable effect on the PSD intensity change is approximated through the scaling rule

$$\sigma_{R.M.S.}(m, \rho) = \sigma^{ref}_{R.M.S.} * SQRT\left((\rho_{ref.} / \rho) * (m / m_{ref})^3 \right) \quad (13)$$

where m and ρ are mass flow rate and density respectively. The implied assumption in the scaling rule is the PSD shape does not change at a power level due to small perturbations caused by the variability in the engine system but the intensity scales according to equation 13.

In a closed coupled engine system such as Space Shuttle main Engine, many engine system level independent random variables affect the dependent variables of interest identified earlier. However, based on the influence coefficient value, the following dominant engine system primitive variables were identified. They are

1. Main combustion chamber hot gas injector resistance
2. Hot gas manifold flow resistance oxidizer side
3. High pressure fuel pump turbine efficiency multiplier
4. High pressure oxidizer pump turbine efficiency multiplier

5. Main combustion chamber throat diameter
6. High pressure fuel pump efficiency multiplier
7. High pressure oxidizer pump efficiency multiplier

11 The Fatigue Damage Computation Module::

The fatigue damage due the dynamic pressure environment was computed using damage computation methodology as described below. This has been implemented in the fatigue module. The Fatigue program has been in use for HCF (High Cycle Fatigue) damage prediction on the Shuttle Program at Rocketdyne for about two decades.

Under spectrum loading, the HCF damage is conceptually the summation of all the damage fractions and can be represented as

$$D = \int_{-\infty}^{\infty} \frac{h(\sigma_{eq}^{alt})}{n_{f0}(\sigma_{eq}^{alt})} d\sigma_{eq}^{alt} \tag{14}$$

where the symbols are defined as follows:

D	Damage
$h(\sigma_{eq}^{alt})$	Probability distribution function (histogram for test data) of alternating stresses
$\sigma_{eq}^{alt}(\sigma^{alt}, \sigma_{mean})$	Equivalent alternating stress accounting for mean stress correction. Given the alternating stress (σ^{alt}) and the mean stress (σ_{mean}), the mean stress correction model predicts the equivalent alternating stress that would cause the same damage at zero mean ($R = -1$) as the current alternating and mean stress.
n_{f0}	Fully reversed ($R = -1$) fatigue curve

The numerical accuracy of the failure integral evaluation can be assessed efficiently by dividing the range of alternating stresses and calculating the integral with block rule (0th order), trapezoidal rule (first order) and Simpson quadrature (second order) using the same set of integrands. When an external histogram file is used, the number of bins may not be even precluding the use of the second order integration scheme. The accuracy measure reported by the program is the ratio of the integrals obtained with the two highest order schemes. When this measure is between 0.95 and 1.05, the damage calculation is considered accurate. Currently, there is no attempt to adaptively refine the discretization to achieve a preset accuracy level. Instead, the number of divisions has been set based on experimentation with a large number of fatigue curves and load spectra.

It has traditionally been assumed in earlier versions of Fatigue that the HCF load is narrow banded characterized with rms value and an expected frequency and the hardware can be locally approximated as a single degree of freedom system. In this case it can be shown that the strain amplitudes follow a Rayleigh distribution whose

parameter is the rms of the exciting signal. The cumulative distribution function (F) and the probability density function (f) of the Rayleigh distribution are given below.

$$F(x) = 1 - e^{-\frac{1}{2}\left(\frac{x}{c}\right)^2}, \quad f = \frac{x}{c^2} e^{-\frac{1}{2}\left(\frac{x}{c}\right)^2} \tag{15}$$

where c is the parameter of the distribution. In the numerical calculations the density function must be truncated. It is customary to assume that the truncation point at $3c$ is sufficiently accurate.

A simple mean estimation method ignoring both monotonic and cyclic strain hardening in the material has been used in the probabilistic failure assessment. The assumption is that the peak stress does not exceed yield stress during the random cycles. Consequently, the mean stress is adjusted as follows:

if $k\sigma_{alt}^{\max} \geq FTY$ then

$\sigma_{mean}^{adj} = 0$

else

$$\sigma_{mean}^{adj} = \begin{cases} FTY - k\sigma_{alt}^{max} & if\ k(\sigma_{mean} + \sigma_{alt}^{max}) > FTY \\ k\sigma_{mean} & otherwise \end{cases} \tag{16}$$

where k is a combined stress concentration, transfer and offset factor and FTY is the yield stress.

When the loading has small amplitude and the number of cycles is high, the spectrum is repeated many times in the duration of the load. Therefore, mean stress shakedown occurs early in the life of the part, and constant mean stress is appropriate.

The linear Goodman diagram assumes that the constant life curves are straight lines anchored at the ultimate stress. The modified Goodman diagram introduces a yield cut-off criterion corresponding to the requirement that the maximum stress peak is not to exceed yield.

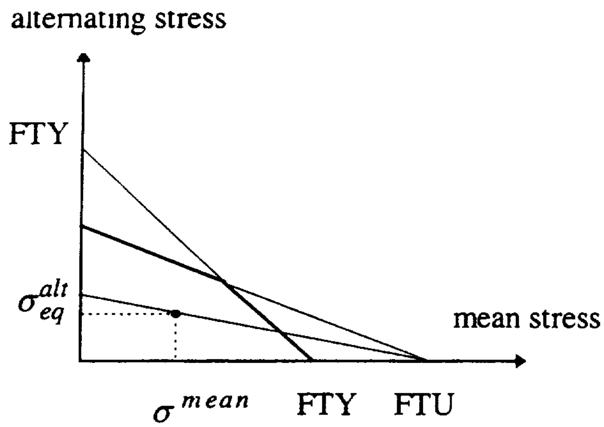


Figure 24 Modified Goodman diagram

The equivalent alternating stress that projects a given set of mean and alternating stresses back to the ordinate at zero mean is calculated by examining the geometry of the Goodman diagram:

$$\frac{\sigma_{equ}^{alt}}{\sigma^{alt}} = \frac{1}{1 - \left(\dfrac{\sigma^{mean}}{\sigma^{ultimate}} \right)} \tag{17}$$

It can be observed that when the mean stress is constant for all cycles, the Goodman model maps the original load spectrum into a distribution of equivalent alternating stresses via linear scaling. More recent experimental data obtained at various mean stresses indicate that the constant life curves may not be straight lines, a material behavior that introduces further nonlinearity into the damage calculation process.

The above outlined damage prediction methodology has been implemented in a library that has been linked with NESSUS. The user defined response evaluator function (UZFUNC) calls the damage method in the fatigue library. While loading uncertainty variables affect the dynamic analysis, material uncertainty variables only affect damage calculation. Nominal material properties are communicated to the response evaluator through constants in the NESSUS PFEM deck.

12. 0 Assembly of the NESUS, CLS and Fatigue Codes and The Computational Results for the Baseline Case:

The codes described in section 9, 10 and 11 were assembled as shown in Figure 25 to perform both the nominal and probabilistic analysis of HEX turn around vane. The analyses were performed for both the baseline case which experienced failures and the for the new redesigned thicker vanes (Figure 3).

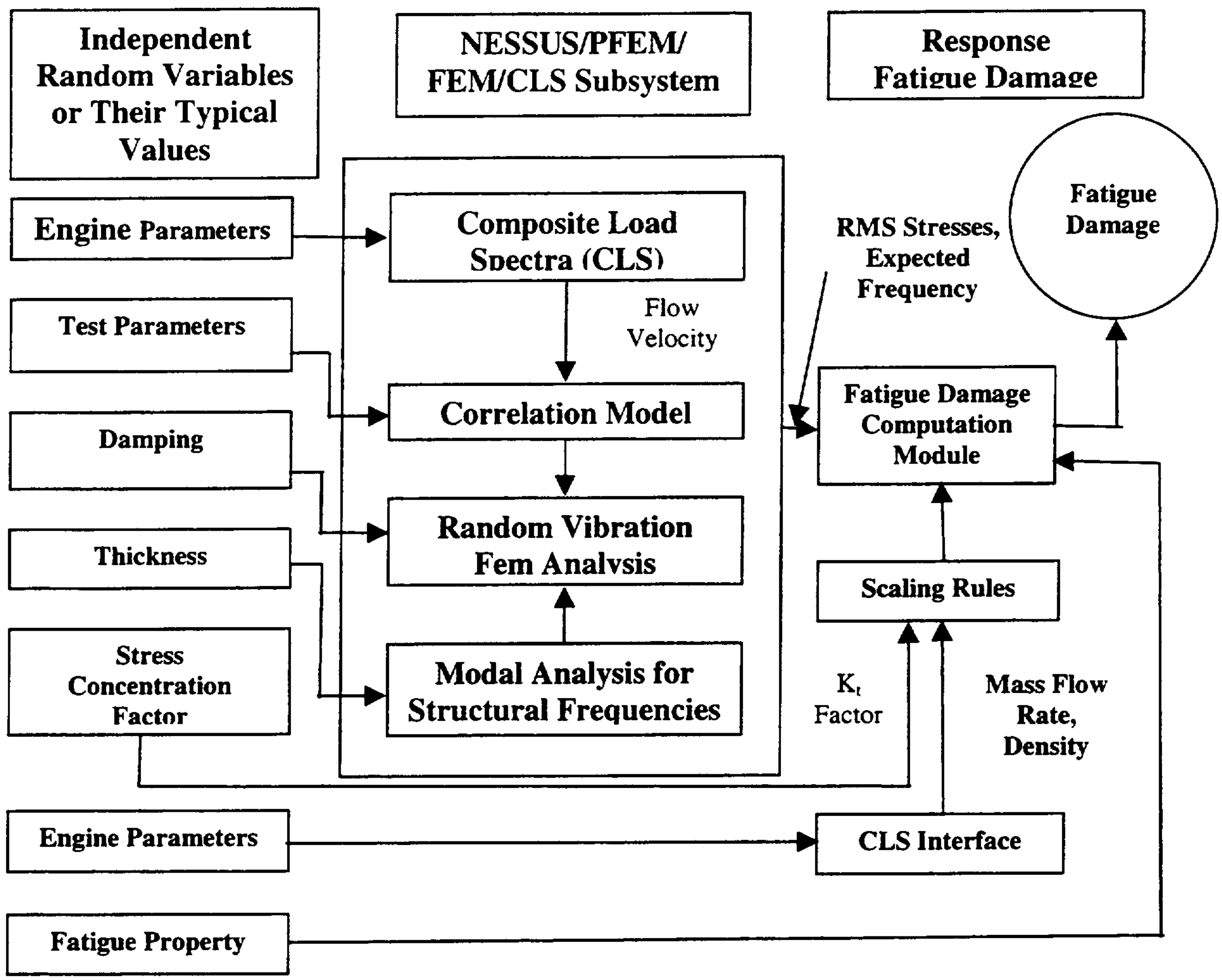


Figure 25. NESSUS/CLS/FATIGUE System Integration Model

Analyses were first carried out using the assembled NESSUS system with typical values for the variables for the baseline case that experienced failures with ATD environment. The RMS stress results from the NESSUS code were compared with the SAFER code results and with experimentally observed strain gage data (Table 5 and Table 6). The strain gage locations were at the leading edge on the inner vane near the support where the cracks originated. They were also located at the trailing and mid span locations. The identified strain gages in Table 5 were also located at different bays. The analytical results were in agreement when known correction factors due to partial loading of the finite element model (two bays loaded only; factor verified with full 360 degree solution) was applied to the analytical results and the large gage correction factor (verified) were applied to the experimental results. As a further check on the analytical results, the predicted stresses were further compared with experimental data at the inner vane trailing edge and at the mid span outer vane (Table 6). This provided the confidence that the analytical models with the new correlation model provided good results. This is because, in general, it is not possible to correlate with field data (several locations) with a single correction factor. The analytical results also correctly predicted the maximum stresses at the observed failure locations (Figure 26). This should be

contrasted with past dynamic analyses using simple distance dependent correlation model only, which failed to predict failure-causing stresses at the failure locations.

Further confidence in the analysis models was obtained when the models were run with Rocketdyne pump environment. The results were consistent with the no failure history. The stresses at the failure locations for the Rocketdyne pump environment were less by a factor of 3.5 when compared to the ATD pump environment. The major differences between the ATD environment and the Rocketdyne environment were the flow velocity changes and the PSD intensity changes. Typical values for the velocity were for ATD 4925 inches/sec and for Rocketdyne 4139 inches/sec. The PSD intensity for the two environments for the inner and outer vanes is shown in Figure 27 and Figure 28 respectively.

Table 5 Comparison of Analytical Stress Results with Experimental Data
Response at 109% Power Level
Leading Edge Inner Vane near Support
E=25.5E6; Large Strain gage Effect Factor 3.0
Analytical results use Cyclic Symmetry RSS Load Factor 2.0
NESSUS results use an additional Coarse Model Correction factor 1.77

Basis	Strain (micro inch)	RMS Stress Hoop Direction	Expected Frequency	Expected Cycle
Sg2	75	5738	4120	4459
Sg3	93	7115	3932	4388
Sg8	101	7727	3946	4318
Sg9	123	9408	4000	4300
Sg-Average	98	7497	4000	4367
SAFER Average	.	7360	4500	4650
NESSUS Six Bay	.	7229	.	.

Table 6 Comparison of Analytical Stress Results with Experimental Data
Response at 109% Power Level
Trailing Edge Inner Vane Near Support And
Leading Edge Outer Vane Midspan
E=25.5E6;
Analytical Results Use Cyclic Symmetry RSS Load Factor 2.0
NESSUS results use an additional Coarse Model Correction factor 1.77

Basis	Strain (Micro-inch)	RMS Sx Hoop Direction	Expected Frequency	Expected Cycle
Sg11 (L.E., Outer, Mid-span)	100	2550	3638	4017
SAFER-Average	-	2300	3850	4200
NESSUS Six bay	-	2994	-	-
Sg2(T.E., Inner Vane, Near Support)	148	3774	3393	3842
SAFER-Average	-	5800	3800	4200
NESSUS Six bay	-	6152	-	-
SAFER Maximum	-	6380	-	-

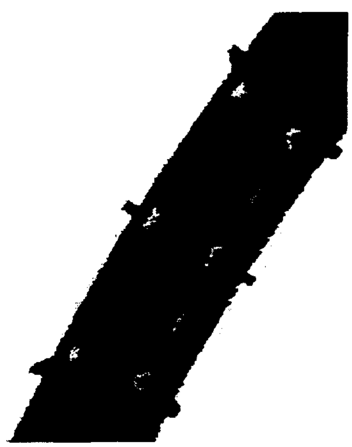


Figure 26. Hoop Stress Contours with Maximum Stresses Predicted by Analysis at the Failure Location Inner Vane Leading Edge

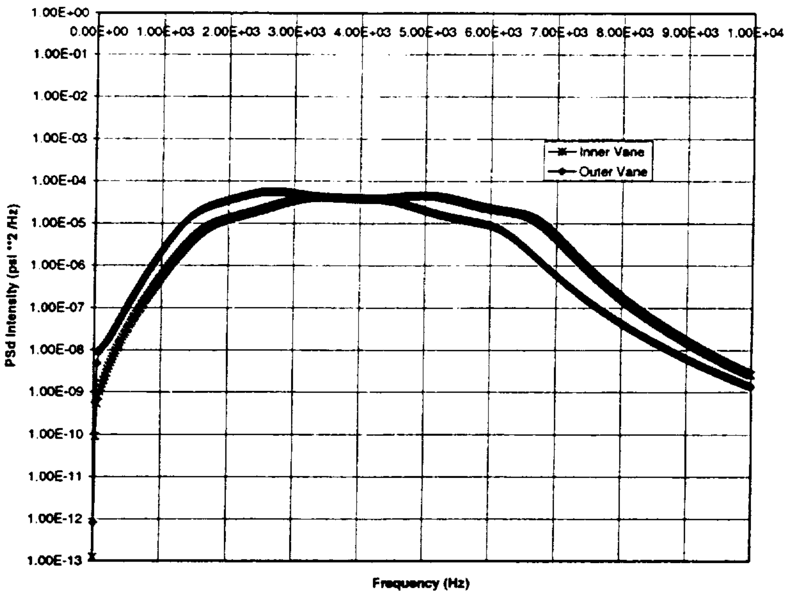


Figure 27. PSD Intensity on the Inner and Outer Vanes for the ATD Environment

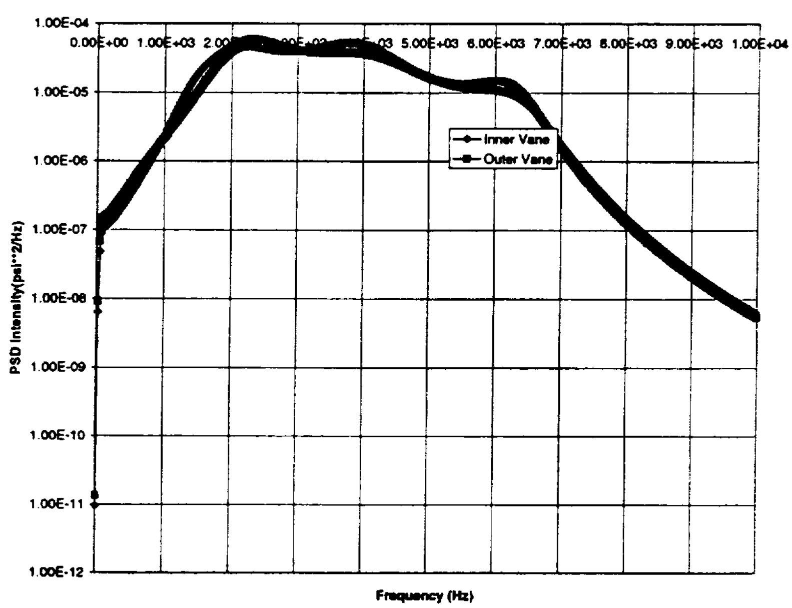


Figure 28. PSD Intensity on the Inner and Outer vanes for the Rocketdyne Environment

Appendix A contains an annotated NESSUS finite element input deck. Some of the analysis features that should be mentioned are

- The thickness of the shell elements in the finite element model defined as nodal properties
- The extremely low modal damping values (based on ping tests on the component) used in the analysis 0.005

- The use of the elaborate frequency band discretization scheme available in NESSUS to perform the numerical quadrature over user defined macro frequency bands including multi-point numerical integration within a band
- The variable bin width macro bands over the frequency of interest to capture the dynamic response accurately but yet covering the full frequency spectrum. The effective bin with being approximately 2 Hz between 3000 to 5000 Hz.
- PSD intensity defined very accurately with 495 points between 1 to 1000 Hz
- The direction of the flow defined as a constant vector within the two bays of the vane
- The different PSD intensities for the inner vane and the outer vane
- The dynamic pressure loading on the inner and outer vane analyzed as two separate spectral cases resulting in reduction of computational effort
- A low typical K_t (stress concentration) factor of 1.3. The maximum stress occurs at the top surface of the inner vane where the stress concentration effects are less.

13. Probabilistic Analysis of the Base Line Case

The first step in the probabilistic analysis was the identification of the random variables. The engine system random variables and their statistics (Table 7) were obtained from the CLS knowledge and influence coefficient databases. The CLS load databases were populated and is continually updated using engine hot fire engine tests. The independent engine system variables with the largest effect on the HEX turn around vane dynamic environment were chosen for the analysis and were identified in section 10. The uncertainty in the convection velocity multiplier to flow stream velocity was obtained from expert's opinion.

Table 7 Engine System Load Random Variables

Variable Pneumonic	Description	Mean Value	Standard Deviation	Distribution Type
MCC-HGIR	MCC Hot Gas Injector Resistance	1.88E-03	4.7E-05	Normal
HGM-O-R	Hot gas Manifold Oxidizer Side Resistance	4.213E-3	2.1065E-4	Normal
HPFT-EM	High Pressure Fuel Turbine Efficiency Multiplier	0.994762	9.94762E-3	Normal
HPOT-EM	High Pressure Oxidizer Turbine Efficiency Multiplier	0.960487	9.60487E-3	Normal
MCC-TH-D	MCC Throat Diameter	1.02897E+0 1	1.02897E- 02	Normal
HPFP-EM	High pressure Fuel Pump Efficiency Multiplier	1.0142	8.1136E-3	Normal
HPOP-EM	High Pressure Oxidizer Pump Efficiency Multiplier	0.94458	3.778E-3	Normal
CONV	Multiplier Free Stream Velocity to Convection	0.72	0.05	Normal

	velocity			

The statistics for thickness variations of the inner and the outer vanes were obtained from inspection records from a sample size of approximately fifty locations. The damping coefficient of variation, the fatigue property Phi coefficient variation and K_t variations were based on experience and expert opinions. Table 8 summarizes the variations used for the above variables in the analysis.

Table 8
Geometry, Structural System and Material Property Random Variables

Variable Pneumonic	Description	Mean Value	Standard Deviation	Distribution Type
TH-IN	Inner Vane Thickness	0.052	0.002	Normal
TH-OU	Outer vane Thickness	0.06	0.0024	Normal
DMP-Scale	Modal damping	0.005	0.001	Log-Normal
PHI	Fatigue Curve Intercept Coefficient	1.0	0.07	Normal
KT	Stress Concentration factor	1.30	0.065	Normal

A critical aspect of the probabilistic analysis is the computational efficiency for compute intensive applications such as the Hex vane dynamic response analysis problem. Probabilistic analysis requires repeated function evaluations to obtain the probabilistic properties of response quantities. Hence strategies were used to reduce the computational burden. The Advanced Mean Value First Order Method with iterations (AMV+) implemented in NESUUS/FPI was used to compute the probabilistic response. The method requires N+1 perturbation solutions where N are the number of random variables plus at least one additional iteration where for each probability level for which the response value is needed. Multiple iterations can be used to further minimize the errors in the probability calculation. The AMV+ is very efficient to compute point probability estimates as was done in this application as opposed to a very general Monte Carlo Simulation approach. For the class of problems such as the HEX vane problem with thirteen random variables, about fifty to hundred functions evaluations were needed for three probability- response level estimation. This is still a significant computational burden and strategies were employed to reduce the computational burden. The first approach is avoiding redundant computations and then only if computations are needed to perform them more efficiently for small perturbations.

NESSUS/FEM package has some built-in intelligence to avoid redundant computations. For example, when damping coefficient alone is perturbed, the modal

response computations can be skipped. When thickness is perturbed, the modal frequencies need to be recalculated and the subspace iteration algorithm for modal response can be accelerated by using the modal solutions from the unperturbed structure as the initial guess for the subspace iteration algorithm. In this application (Figure 25), the K_t and fatigue property Phi do not affect the finite element responses and hence when they were perturbed the entire finite element response computation can be skipped. The mechanism for achieving this in the NESSUS/PFEM context is the use of "Explicit Variables". Appendix B contains an annotated version of the NESSUS/PFEM deck used in this application. The input was used in conjunction with the modified routine as documented in Appendix C (CLS routines), Appendix D (modified NESSUS routines), Appendix E (Fatigue code routine) and Appendix F (influence coefficient database for Rocketdyne and ATD environments).

The expected fatigue damage (mean value) for the baseline design with ATD environment for 1000 seconds of operation was close to 1.0 predicting the failures experienced in tests. The AMV+ methods also provided probabilistic sensitivity factors as identified in Table 9. The sensitivity of damage to convection velocity reflects the high sensitivity of the rms stresses to the convection velocity variable. The traditional fatigue property uncertainty, stress concentration factor uncertainty, damping uncertainty and thickness variations are ranked in that order to fatigue damage failure probability. A range of values is reported, as the sensitivity factors are nonlinear with respect to probability levels. The probabilistic analysis for the base line also provided the ranking of the random variables to the RMS level

Table 9
Probabilistic Sensitivity Factors For Fatigue Damage
Base Line Design with ATD Environment

Random Variable	Probabilistic Sensitivity Factors
Convection Velocity (CONV)	0.8 to 0.95
Fatigue Property (PHI)	0.13 to 0.31
Stress Concentration Factor (KT)	0.14 to 0.29
Structural Damping	0.12 to 0.29
Thickness (TH-IN, TH-OUT)	0.10 to 0.23

Table 10
Probabilistic Sensitivity Factors for RMS Hoop Stress
Probability Level 0.5

Random Variable	Probabilistic Sensitivity Factors

Convection Velocity	**0.82**
Structural damping	**0.44**
Inner Vane Thickness	**0.27**
Outer Vane Thickness	**0.21**

Modifications were performed to the NESUSUS6.1 code to improve the computational speed in the basic dynamic response analysis as well as new user defined subroutines were added as per system shown in Figure 25.

14. Deterministic and Probabilistic Analysis of Redesign:

As a first step the deterministic analysis of the redesigned turn around vane was conducted. The redesigned essentially had the global geometry of the original vane except for the thickened inner vanes (0.07" Vs 0.052") and thickened outer vane (0.07" Vs 0.06"). More significantly the redesign had tapered thickening of inner and outer vanes near the web support (0.07" to 0.151") as depicted in Figure 3. This new geometry is reflected in the NESSUS/FEM deck shown in Appendix G.

The results from the deterministic analysis with typical values for the random variables showed considerable less stresses through out the inner vane than the base line case and the location of the maximum stress shifted to the mid span of the trailing edge (Figure 28).

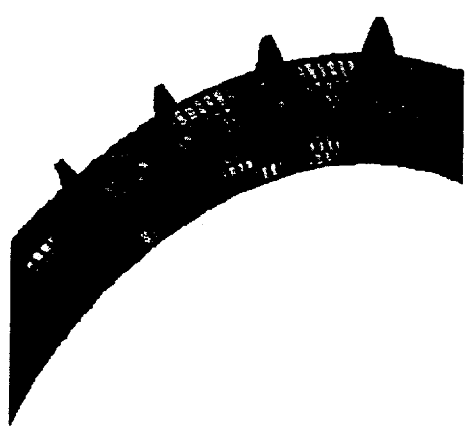


Figure 28. RMS Hoop Stress contours for the Redesigned Vane Maximum Stress Trailing Edge mid Span

The maximum stress value at the mid span was one half the value of the stress at the support for the base line case

A probabilistic analysis of the redesigned vane for the rms hoop stresses at the location of the maximum stress (inner vane trailing edge was conducted). As the maximum stress was away from the stress raisers stress concentration factor (KT) was not considered as a random variable. The probabilistic sensitivity factors obtained from the analysis are summarized in Table 11 for the probability level of 0.5 (expected median value). The stress response is dominated by the uncertainty in damping and to much less extent on the convection velocity factor. As expected the sensitivity to the inner vane thickness is higher than the outer vane.

Table 11
Probabilistic Sensitivity Factors for the Hoop RMS Stress
Probability level 0.5

Random variable	Probabilistic Sensitivity factor
Structural Damping	0.71
Convection Velocity	0.57
Inner Vane Thickness	0.37
Outer Vane Thickness	0.10

After applying correction factors to the NESSUS/FEM results, the maximum predicted hoop stress in the redesigned vane is 1500 psi, which is well below the minimum thresh hold needed to compute any measurable fatigue damage. Thus the analysis results predicted infinite fatigue life for the part.

15. Operational and Test Experience of the redesigned Vane:

The redesigned vane has not experienced any failures in the test and flight history (Table 12) with about seven units in service with different accumulated time. Since there were no strain gage measurements on the redesigned vane during hot fire testing, it has not been possible to verify the analytical predictions of the stresses with test results.

Table 12 Hot Fire Time Accumulation History
Redesigned HEX Turn around Vane

Description	Starts	Seconds
Flight		
Unit 1	5	2585
Unit 2	4	1798
Unit 3	4	1920

Unit 4	**3**	**1554**
Flight Total	**16**	**7857**
Ground Test		
Unit 5	**33**	**15171**
Unit 6	**87**	**43648**
Unit 7	**9**	**4906**
Ground Test Total	**129**	**63725**

16. Summary and Conclusions:

Probabilistic analysis identified the ranking of the random variables that control the variability of the Hex turn around vane dynamic structural response. When resonance conditions were present such as in the base line case, the convection velocity dominated the uncertainty of the structural response. When detuning occurred either due to change in the velocity (Rocketdyne base line case) or due to structural changes (redesign) the structural stress responses reduced drastically. In the detuned cases the uncertainty in structural response was dominated by the uncertainty in damping followed velocity and geometry variables such as thickness.

For flow induced vibration cases, use of the appropriate correlation model is as important if not more as the determination of PSD. In design cases as illustrated in the HEX turn around vane, simplistic correlation models (such only distance dependent models) can miss the physics of the problem entirely and miss the response prediction by several orders of magnitude.

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Appendix A

NESSUS Deterministic Annotated Finite Element Analysis Deck or the Base Line Case

```
C Start FEM DECK Here
C
*FEM
C HEX TURAROUND VANE
*DISP
*BOUNDARY    24
*CONSTITUTIVE  0
*DUPLICATENODES 84
*ELEMENTS      740
 75
*FORCE 792
*FREQUENCYBANDS 4 3  0  1
*MODAL  50 100
 50
*NODES  942
*OPTIMIZE  10
*POST
*PRINT
*MONITOR 1
C 11 by 6  nodes per two vanes * 6 DOF
C number of excitation points is (11*6 )*2*6 = 792
C two spectral cases one for inner vane and one for outer vane
*PSD  2  792   495
*COEF 10
*END
C The first seven are typical values of CLS load variables that are
C passed to CLS routines. The eighth variable is the multiplier to
C free stream velocity to obtain the convection velocity
*COEF
 1  1.88E-03
 2  4.213E-3
 3  1.01488
 4  0.960487
 5  1.02897E+01
 6  1.0142
 7  0.94458
 8  0.72
 9  0.0
10  0.0
```

```
C Typical thickness of the inner vane is 0.052 and the outer vane is 0.06
C and the web is 0.125
*COORDINATES
C
C ***************************************************
C *              QUAD-MODEL              *
C ***************************************************
C
   1   0.00000000   5.54800000   4.80730000   0.052000
   2   0.21440000   5.49510000   4.76150000   0.052000
   3   0.41910000   5.42400000   4.69990000   0.052000
   4   0.61170000   5.33640000   4.62400000   0.052000
   5   0.78950000   5.23210000   4.53360000   0.052000
   6   0.95030000   5.11270000   4.43010000   0.052000
   7   0.00000000   5.40840000   4.96380000   0.052000
   8   0.21440000   5.35680000   4.91640000   0.052000
   9   0.41910000   5.28760000   4.85290000   0.052000
  10   0.61170000   5.20210000   4.77440000   0.052000
  11   0.78950000   5.10050000   4.68120000   0.052000
  12   0.95030000   4.98400000   4.57430000   0.052000
  13   0.00000000   5.26450000   5.11620000   0.052000
  14   0.21440000   5.21420000   5.06740000   0.052000
  15   0.41910000   5.14690000   5.00190000   0.052000
  16   0.61170000   5.06370000   4.92110000   0.052000
  17   0.78950000   4.96470000   4.82490000   0.052000
  18   0.95030000   4.85140000   4.71480000   0.052000
  19   0.00000000   5.11620000   5.26450000   0.052000
  20   0.21440000   5.06740000   5.21420000   0.052000
  21   0.41910000   5.00200000   5.14690000   0.052000
  22   0.61170000   4.92110000   5.06370000   0.052000
  23   0.78950000   4.82490000   4.96470000   0.052000
  24   0.95030000   4.71480000   4.85140000   0.052000
  25   0.00000000   4.96380000   5.40840000   0.052000
  26   0.21440000   4.91650000   5.35680000   0.052000
  27   0.41910000   4.85290000   5.28760000   0.052000
  28   0.61170000   4.77450000   5.20210000   0.052000
  29   0.78950000   4.68120000   5.10050000   0.052000
  30   0.95030000   4.57430000   4.98400000   0.052000
  31   0.00000000   4.80740000   5.54790000   0.052000
  32   0.21440000   4.76150000   5.49510000   0.052000
  33   0.41910000   4.69990000   5.42400000   0.052000
  34   0.61170000   4.62390000   5.33630000   0.052000
  35   0.78950000   4.53360000   5.23200000   0.052000
  36   0.95030000   4.43010000   5.11260000   0.052000
  37   0.00000000   4.64700000   5.68300000   0.052000
  38   0.21440000   4.60260000   5.62880000   0.052000
```

85	0.00000000	3.23910000	6.58780000	0.052000
86	0.21440000	3.20810000	6.52500000	0.052000
87	0.41910000	3.16660000	6.44060000	0.052000
88	0.61170000	3.11550000	6.33650000	0.052000
89	0.78950000	3.05460000	6.21260000	0.052000
90	0.95030000	2.98490000	6.07090000	0.052000
91	0.00000000	3.04950000	6.67760000	0.052000
92	0.21440000	3.02050000	6.61390000	0.052000
93	0.41910000	2.98140000	6.52840000	0.052000
94	0.61170000	2.93330000	6.42290000	0.052000
95	0.78950000	2.87600000	6.29740000	0.052000
96	0.95030000	2.81030000	6.15370000	0.052000
97	0.00000000	2.85760000	6.76200000	0.052000
98	0.21440000	2.83040000	6.69750000	0.052000
99	0.41910000	2.79380000	6.61080000	0.052000
100	0.61170000	2.74860000	6.50410000	0.052000
101	0.78950000	2.69490000	6.37700000	0.052000
102	0.95030000	2.63340000	6.23140000	0.052000
103	0.00000000	2.66340000	6.84080000	0.052000
104	0.21440000	2.63800000	6.77550000	0.052000
105	0.41910000	2.60390000	6.68800000	0.052000
106	0.61170000	2.56180000	6.57990000	0.052000
107	0.78950000	2.51170000	6.45120000	0.052000
108	0.95030000	2.45440000	6.30410000	0.052000
109	0.00000000	2.46690000	6.91400000	0.052000
110	0.21440000	2.44340000	6.84820000	0.052000
111	0.41910000	2.41180000	6.75960000	0.052000
112	0.61170000	2.37280000	6.65030000	0.052000
113	0.78950000	2.32650000	6.52040000	0.052000
114	0.95030000	2.27340000	6.37160000	0.052000
115	0.00000000	2.26850000	6.98170000	0.052000
116	0.21440000	2.24690000	6.91510000	0.052000
117	0.41910000	2.21780000	6.82570000	0.052000
118	0.61170000	2.18200000	6.71540000	0.052000
119	0.78950000	2.13930000	6.58410000	0.052000
120	0.95030000	2.09050000	6.43390000	0.052000
121	0.00000000	2.06820000	7.04360000	0.052000
122	0.21440000	2.04850000	6.97650000	0.052000
123	0.41910000	2.02200000	6.88630000	0.052000
124	0.61170000	1.98930000	6.77500000	0.052000
125	0.78950000	1.95040000	6.64260000	0.052000
126	0.95030000	1.90600000	6.49100000	0.052000
127	0.00000000	1.86620000	7.09980000	0.052000
128	0.21440000	1.84840000	7.03210000	0.052000
129	0.41910000	1.82450000	6.94120000	0.052000
130	0.61170000	1.79510000	6.82900000	0.052000

39	0.41910000	4.54320000	5.55600000	0.052000
40	0.61170000	4.46970000	5.46630000	0.052000
41	0.78950000	4.38240000	5.35940000	0.052000
42	0.95030000	4.28230000	5.23710000	0.052000
43	0.00000000	4.48280000	5.81340000	0.052000
44	0.21440000	4.44000000	5.75800000	0.052000
45	0.41910000	4.38270000	5.68350000	0.052000
46	0.61170000	4.31190000	5.59160000	0.052000
47	0.78950000	4.22750000	5.48230000	0.052000
48	0.95030000	4.13100000	5.35730000	0.052000
49	0.00000000	4.31490000	5.93900000	0.052000
50	0.21440000	4.27370000	5.88240000	0.052000
51	0.41910000	4.21850000	5.80630000	0.052000
52	0.61170000	4.15040000	5.71250000	0.052000
53	0.78950000	4.06930000	5.60080000	0.052000
54	0.95030000	3.97640000	5.47300000	0.052000
55	0.00000000	4.14360000	6.05980000	0.052000
56	0.21440000	4.10410000	6.00200000	0.052000
57	0.41910000	4.05100000	5.92440000	0.052000
58	0.61170000	3.98550000	5.82860000	0.052000
59	0.78950000	3.90770000	5.71480000	0.052000
60	0.95030000	3.81840000	5.58430000	0.052000
61	0.00000000	3.96880000	6.17560000	0.052000
62	0.21440000	3.93100000	6.11680000	0.052000
63	0.41910000	3.88020000	6.03770000	0.052000
64	0.61170000	3.81750000	5.94010000	0.052000
65	0.78950000	3.74290000	5.82400000	0.052000
66	0.95030000	3.65750000	5.69110000	0.052000
67	0.00000000	3.79090000	6.28650000	0.052000
68	0.21440000	3.75470000	6.22650000	0.052000
69	0.41910000	3.70620000	6.14600000	0.052000
70	0.61170000	3.64630000	6.04670000	0.052000
71	0.78950000	3.57510000	5.92850000	0.052000
72	0.95030000	3.49340000	5.79320000	0.052000
73	0.00000000	3.60990000	6.39210000	0.052000
74	0.21440000	3.57540000	6.33120000	0.052000
75	0.41910000	3.52920000	6.24930000	0.052000
76	0.61170000	3.47220000	6.14830000	0.052000
77	0.78950000	3.40430000	6.02820000	0.052000
78	0.95030000	3.32660000	5.89060000	0.052000
79	0.00000000	3.42580000	6.49260000	0.052000
80	0.21440000	3.39310000	6.43070000	0.052000
81	0.41910000	3.34930000	6.34760000	0.052000
82	0.61170000	3.29510000	6.24500000	0.052000
83	0.78950000	3.23080000	6.12290000	0.052000
84	0.95030000	3.15700000	5.98320000	0.052000

131	0.78950000	1.76000000	6.69550000	0.052000
132	0.95030000	1.71980000	6.54280000	0.052000
133	0.00000000	1.66270000	7.15020000	0.052000
134	0.21440000	1.64690000	7.08210000	0.052000
135	0.41910000	1.62560000	6.99040000	0.052000
136	0.61170000	1.59930000	6.87760000	0.052000
137	0.78950000	1.56810000	6.74300000	0.052000
138	0.95030000	1.53220000	6.58920000	0.052000
139	0.00000000	1.45790000	7.19480000	0.052000
140	0.21440000	1.44400000	7.12610000	0.052000
141	0.41910000	1.42530000	7.03400000	0.052000
142	0.61170000	1.40220000	6.92040000	0.052000
143	0.78950000	1.37480000	6.78510000	0.052000
144	0.95030000	1.34350000	6.63020000	0.052000
145	0.00000000	1.25190000	7.23350000	0.052000
146	0.21440000	1.23990000	7.16450000	0.052000
147	0.41910000	1.22390000	7.07180000	0.052000
148	0.61170000	1.20410000	6.95760000	0.052000
149	0.78950000	1.18060000	6.82160000	0.052000
150	0.95030000	1.15360000	6.66590000	0.052000
151	0.00000000	1.04480000	7.26630000	0.052000
152	0.21440000	1.03480000	7.19700000	0.052000
153	0.41910000	1.02140000	7.10390000	0.052000
154	0.61170000	1.00480000	6.98910000	0.052000
155	0.78950000	0.98529000	6.85260000	0.052000
156	0.95030000	0.96276000	6.69610000	0.052000
157	0.00000000	0.83681000	7.29310000	0.052000
158	0.21440000	0.82879000	7.22360000	0.052000
159	0.41910000	0.81814000	7.13020000	0.052000
160	0.61170000	0.80486000	7.01500000	0.052000
161	0.78950000	0.78918000	6.87790000	0.052000
162	0.95030000	0.77121000	6.72090000	0.052000
163	0.00000000	0.62826000	7.31410000	0.052000
164	0.21440000	0.62228000	7.24430000	0.052000
165	0.41910000	0.61423000	7.15070000	0.052000
166	0.61170000	0.60427000	7.03510000	0.052000
167	0.78950000	0.59244000	6.89760000	0.052000
168	0.95030000	0.57892000	6.74020000	0.052000
169	0.00000000	0.41906000	7.32900000	0.052000
170	0.21440000	0.41506000	7.25910000	0.052000
171	0.41910000	0.40969000	7.16530000	0.052000
172	0.61170000	0.40311000	7.04950000	0.052000
173	0.78950000	0.39524000	6.91170000	0.052000
174	0.95030000	0.38623000	6.75400000	0.052000
175	0.00000000	0.20965000	7.33800000	0.052000
176	0.21440000	0.20770000	7.26800000	0.052000

177	0.41910000	0.20495000	7.17410000	0.052000
178	0.61170000	0.20169000	7.05810000	0.052000
179	0.78950000	0.19771000	6.92020000	0.052000
180	0.95030000	0.19314000	6.76230000	0.052000
181	0.00000000	-0.00004067	7.34100000	0.052000
182	0.21440000	-0.00001236	7.27100000	0.052000
183	0.41910000	-0.00000560	7.17700000	0.052000
184	0.61170000	0.00006397	7.06100000	0.052000
185	0.78950000	-0.00001954	6.92300000	0.052000
186	0.95030000	0.00001577	6.76490000	0.052000
187	0.00000000	-0.20967000	7.33800000	0.052000
188	0.21440000	-0.20766000	7.26800000	0.052000
189	0.41910000	-0.20495000	7.17400000	0.052000
190	0.61170000	-0.20161000	7.05810000	0.052000
191	0.78950000	-0.19773000	6.92020000	0.052000
192	0.95030000	-0.19321000	6.76220000	0.052000
193	0.00000000	-0.41908000	7.32910000	0.052000
194	0.21440000	-0.41508000	7.25910000	0.052000
195	0.41910000	-0.40974000	7.16530000	0.052000
196	0.61170000	-0.40307000	7.04950000	0.052000
197	0.78950000	-0.39520000	6.91170000	0.052000
198	0.95030000	-0.38621000	6.75390000	0.052000
199	0.00000000	-0.62822000	7.31410000	0.052000
200	0.21440000	-0.62222000	7.24440000	0.052000
201	0.41910000	-0.61418000	7.15060000	0.052000
202	0.61170000	-0.60422000	7.03520000	0.052000
203	0.78950000	-0.59244000	6.89760000	0.052000
204	0.95030000	-0.57888000	6.74020000	0.052000
205	0.00000000	-0.83679000	7.29320000	0.052000
206	0.21440000	-0.82879000	7.22360000	0.052000
207	0.41910000	-0.81810000	7.13020000	0.052000
208	0.61170000	-0.80494000	7.01500000	0.052000
209	0.78950000	-0.78916000	6.87780000	0.052000
210	0.95030000	-0.77110000	6.72090000	0.052000
211	0.00000000	-1.04470000	7.26620000	0.052000
212	0.21440000	-1.03480000	7.19700000	0.052000
213	0.41910000	-1.02140000	7.10400000	0.052000
214	0.61170000	-1.00490000	6.98920000	0.052000
215	0.78950000	-0.98520000	6.85260000	0.052000
216	0.95030000	-0.96279000	6.69610000	0.052000
217	0.00000000	-1.25180000	7.23350000	0.052000
218	0.21440000	-1.23990000	7.16450000	0.052000
219	0.41910000	-1.22380000	7.07190000	0.052000
220	0.61170000	-1.20400000	6.95760000	0.052000
221	0.78950000	-1.18050000	6.82160000	0.052000
222	0.95030000	-1.15360000	6.66590000	0.052000

223	0.00000000	-1.45780000	7.19470000	0.052000
224	0.21440000	-1.44390000	7.12620000	0.052000
225	0.41910000	-1.42520000	7.03400000	0.052000
226	0.61170000	-1.40220000	6.92030000	0.052000
227	0.78950000	-1.37480000	6.78520000	0.052000
228	0.95030000	-1.34340000	6.63030000	0.052000
229	0.00000000	-1.66270000	7.15020000	0.052000
230	0.21440000	-1.64690000	7.08200000	0.052000
231	0.41910000	-1.62560000	6.99050000	0.052000
232	0.61170000	-1.59930000	6.87750000	0.052000
233	0.78950000	-1.56800000	6.74300000	0.052000
234	0.95030000	-1.53230000	6.58920000	0.052000
235	0.00000000	-1.86620000	7.09980000	0.052000
236	0.21440000	-1.84840000	7.03210000	0.052000
237	0.41910000	-1.82450000	6.94120000	0.052000
238	0.61170000	-1.79500000	6.82900000	0.052000
239	0.78950000	-1.75990000	6.69560000	0.052000
240	0.95030000	-1.71970000	6.54280000	0.052000
241	0.00000000	-2.06820000	7.04370000	0.052000
242	0.21440000	-2.04840000	6.97650000	0.052000
243	0.41910000	-2.02200000	6.88620000	0.052000
244	0.61170000	-1.98930000	6.77490000	0.052000
245	0.78950000	-1.95040000	6.64260000	0.052000
246	0.95030000	-1.90590000	6.49100000	0.052000
247	0.00000000	-2.26850000	6.98170000	0.052000
248	0.21440000	-2.24680000	6.91520000	0.052000
249	0.41910000	-2.21780000	6.82570000	0.052000
250	0.61170000	-2.18200000	6.71540000	0.052000
251	0.78950000	-2.13930000	6.58410000	0.052000
252	0.95030000	-2.09050000	6.43390000	0.052000
253	0.00000000	-2.46690000	6.91410000	0.052000
254	0.21440000	-2.44340000	6.84820000	0.052000
255	0.41910000	-2.41180000	6.75960000	0.052000
256	0.61170000	-2.37280000	6.65040000	0.052000
257	0.78950000	-2.32650000	6.52040000	0.052000
258	0.95030000	-2.27340000	6.37160000	0.052000
259	0.00000000	-2.66340000	6.84080000	0.052000
260	0.21440000	-2.63800000	6.77560000	0.052000
261	0.41910000	-2.60390000	6.68800000	0.052000
262	0.61170000	-2.56180000	6.57990000	0.052000
263	0.78950000	-2.51170000	6.45130000	0.052000
264	0.95030000	-2.45440000	6.30410000	0.052000
265	0.00000000	-2.85760000	6.76200000	0.052000
266	0.21440000	-2.83030000	6.69750000	0.052000
267	0.41910000	-2.79380000	6.61090000	0.052000
268	0.61170000	-2.74860000	6.50410000	0.052000

269	0.78950000	-2.69490000	6.37700000	0.052000
270	0.95030000	-2.63340000	6.23140000	0.052000
271	0.00000000	-3.04950000	6.67760000	0.052000
272	0.21440000	-3.02050000	6.61400000	0.052000
273	0.41910000	-2.98140000	6.52850000	0.052000
274	0.61170000	-2.93330000	6.42290000	0.052000
275	0.78950000	-2.87600000	6.29740000	0.052000
276	0.95030000	-2.81030000	6.15370000	0.052000
277	0.00000000	-3.23900000	6.58780000	0.052000
278	0.21440000	-3.20810000	6.52500000	0.052000
279	0.41910000	-3.16660000	6.44060000	0.052000
280	0.61170000	-3.11550000	6.33650000	0.052000
281	0.78950000	-3.05460000	6.21280000	0.052000
282	0.95030000	-2.98480000	6.07090000	0.052000
283	0.00000000	-3.42580000	6.49260000	0.052000
284	0.21440000	-3.39310000	6.43070000	0.052000
285	0.41910000	-3.34920000	6.34760000	0.052000
286	0.61170000	-3.29510000	6.24500000	0.052000
287	0.78950000	-3.23080000	6.12290000	0.052000
288	0.95030000	-3.15700000	5.98320000	0.052000
289	0.00000000	-3.60980000	6.39220000	0.052000
290	0.21440000	-3.57540000	6.33120000	0.052000
291	0.41910000	-3.52920000	6.24940000	0.052000
292	0.61170000	-3.47220000	6.14830000	0.052000
293	0.78950000	-3.40430000	6.02810000	0.052000
294	0.95030000	-3.32660000	5.89070000	0.052000
295	0.00000000	-3.79090000	6.28650000	0.052000
296	0.21440000	-3.75470000	6.22650000	0.052000
297	0.41910000	-3.70620000	6.14600000	0.052000
298	0.61170000	-3.64630000	6.04670000	0.052000
299	0.78950000	-3.57500000	5.92850000	0.052000
300	0.95030000	-3.49340000	5.79320000	0.052000
301	0.00000000	-3.96890000	6.17560000	0.052000
302	0.21440000	-3.93100000	6.11680000	0.052000
303	0.41910000	-3.88010000	6.03770000	0.052000
304	0.61170000	-3.81740000	5.94010000	0.052000
305	0.78950000	-3.74280000	5.82400000	0.052000
306	0.95030000	-3.65740000	5.69110000	0.052000
307	0.00000000	-4.14350000	6.05980000	0.052000
308	0.21440000	-4.10410000	6.00200000	0.052000
309	0.41910000	-4.05100000	5.92440000	0.052000
310	0.61170000	-3.98550000	5.82870000	0.052000
311	0.78950000	-3.90770000	5.71480000	0.052000
312	0.95030000	-3.81840000	5.58430000	0.052000
313	0.00000000	-4.31490000	5.93900000	0.052000
314	0.21440000	-4.27380000	5.88240000	0.052000

315	0.41910000	-4.21850000	5.80630000	0.052000
316	0.61170000	-4.15030000	5.71250000	0.052000
317	0.78950000	-4.06920000	5.60080000	0.052000
318	0.95030000	-3.97640000	5.47300000	0.052000
319	0.00000000	-4.48270000	5.81330000	0.052000
320	0.21440000	-4.44000000	5.75790000	0.052000
321	0.41910000	-4.38260000	5.68350000	0.052000
322	0.61170000	-4.31180000	5.59160000	0.052000
323	0.78950000	-4.22750000	5.48230000	0.052000
324	0.95030000	-4.13100000	5.35730000	0.052000
325	0.00000000	-4.64690000	5.68300000	0.052000
326	0.21440000	-4.60260000	5.62880000	0.052000
327	0.41910000	-4.54310000	5.55600000	0.052000
328	0.61170000	-4.46970000	5.46620000	0.052000
329	0.78950000	-4.38240000	5.35940000	0.052000
330	0.95030000	-4.28230000	5.23700000	0.052000
331	0.00000000	-4.80730000	5.54800000	0.052000
332	0.21440000	-4.76150000	5.49510000	0.052000
333	0.41910000	-4.69990000	5.42400000	0.052000
334	0.61170000	-4.62400000	5.33640000	0.052000
335	0.78950000	-4.53360000	5.23210000	0.052000
336	0.95030000	-4.43010000	5.11270000	0.052000
337	0.00000000	-4.96380000	5.40840000	0.052000
338	0.21440000	-4.91640000	5.35680000	0.052000
339	0.41910000	-4.85290000	5.28760000	0.052000
340	0.61170000	-4.77440000	5.20210000	0.052000
341	0.78950000	-4.68120000	5.10050000	0.052000
342	0.95030000	-4.57430000	4.98400000	0.052000
343	0.00000000	-5.11620000	5.26450000	0.052000
344	0.21440000	-5.06740000	5.21420000	0.052000
345	0.41910000	-5.00190000	5.14690000	0.052000
346	0.61170000	-4.92110000	5.06370000	0.052000
347	0.78950000	-4.82490000	4.96470000	0.052000
348	0.95030000	-4.71480000	4.85140000	0.052000
349	0.00000000	-5.26450000	5.11630000	0.052000
350	0.21440000	-5.21420000	5.06740000	0.052000
351	0.41910000	-5.14690000	5.00200000	0.052000
352	0.61170000	-5.06370000	4.92110000	0.052000
353	0.78950000	-4.96470000	4.82490000	0.052000
354	0.95030000	-4.85140000	4.71480000	0.052000
355	0.00000000	-5.40840000	4.96380000	0.052000
356	0.21440000	-5.35680000	4.91650000	0.052000
357	0.41910000	-5.28760000	4.85290000	0.052000
358	0.61170000	-5.20210000	4.77450000	0.052000
359	0.78950000	-5.10050000	4.68120000	0.052000
360	0.95030000	-4.98400000	4.57430000	0.052000

361	0.00000000	-5.54790000	4.80740000	0.052000
362	0.21440000	-5.49510000	4.76150000	0.052000
363	0.41910000	-5.42400000	4.69990000	0.052000
364	0.61170000	-5.33630000	4.62390000	0.052000
365	0.78950000	-5.23200000	4.53360000	0.052000
366	0.95030000	-5.11260000	4.43010000	0.052000
367	0.00000000	6.03920000	5.23300000	0.060000
368	0.33230000	5.90920000	5.12030000	0.060000
369	0.64010000	5.74900000	4.98150000	0.060000
370	0.91850000	5.56080000	4.81850000	0.060000
371	1.16300000	5.34770000	4.63380000	0.060000
372	1.37000000	5.11270000	4.43010000	0.060000
373	0.00000000	5.88730000	5.40330000	0.060000
374	0.33230000	5.76060000	5.28700000	0.060000
375	0.64010000	5.60440000	5.14370000	0.060000
376	0.91850000	5.42090000	4.97530000	0.060000
377	1.16300000	5.21320000	4.78460000	0.060000
378	1.37000000	4.98400000	4.57430000	0.060000
379	0.00000000	5.73060000	5.56920000	0.060000
380	0.33230000	5.60720000	5.44930000	0.060000
381	0.64010000	5.45520000	5.30160000	0.060000
382	0.91850000	5.27670000	5.12810000	0.060000
383	1.16300000	5.07450000	4.93150000	0.060000
384	1.37000000	4.85140000	4.71480000	0.060000
385	0.00000000	5.56920000	5.73060000	0.060000
386	0.33230000	5.44940000	5.60720000	0.060000
387	0.64010000	5.30160000	5.45520000	0.060000
388	0.91850000	5.12810000	5.27660000	0.060000
389	1.16300000	4.93150000	5.07440000	0.060000
390	1.37000000	4.71480000	4.85140000	0.060000
391	0.00000000	5.40330000	5.88730000	0.060000
392	0.33230000	5.28700000	5.76050000	0.060000
393	0.64010000	5.14370000	5.60440000	0.060000
394	0.91850000	4.97530000	5.42090000	0.060000
395	1.16300000	4.78460000	5.21320000	0.060000
396	1.37000000	4.57430000	4.98400000	0.060000
397	0.00000000	5.23310000	6.03920000	0.060000
398	0.33230000	5.12030000	5.90920000	0.060000
399	0.64010000	4.98150000	5.74900000	0.060000
400	0.91850000	4.81840000	5.56080000	0.060000
401	1.16300000	4.63380000	5.34770000	0.060000
402	1.37000000	4.43010000	5.11260000	0.060000
403	0.00000000	5.05850000	6.18610000	0.060000
404	0.33230000	4.94960000	6.05300000	0.060000
405	0.64010000	4.81530000	5.88890000	0.060000
406	0.91850000	4.65770000	5.69610000	0.060000

407	1.16300000	4.47920000	5.47780000	0.060000
408	1.37000000	4.28230000	5.23710000	0.060000
409	0.00000000	4.87970000	6.32800000	0.060000
410	0.33230000	4.77470000	6.19190000	0.060000
411	0.64010000	4.64520000	6.02400000	0.060000
412	0.91850000	4.49310000	5.82680000	0.060000
413	1.16300000	4.32100000	5.60350000	0.060000
414	1.37000000	4.13100000	5.35730000	0.060000
415	0.00000000	4.69700000	6.46480000	0.060000
416	0.33230000	4.59590000	6.32570000	0.060000
417	0.64010000	4.47130000	6.15420000	0.060000
418	0.91850000	4.32490000	5.95280000	0.060000
419	1.16300000	4.15920000	5.72460000	0.060000
420	1.37000000	3.97640000	5.47300000	0.060000
421	0.00000000	4.51050000	6.59640000	0.060000
422	0.33230000	4.41340000	6.45430000	0.060000
423	0.64010000	4.29380000	6.27930000	0.060000
424	0.91850000	4.15320000	6.07380000	0.060000
425	1.16300000	3.99400000	5.84100000	0.060000
426	1.37000000	3.81840000	5.58430000	0.060000
427	0.00000000	4.32030000	6.72240000	0.060000
428	0.33230000	4.22730000	6.57780000	0.060000
429	0.64010000	4.11270000	6.39940000	0.060000
430	0.91850000	3.97800000	6.18990000	0.060000
431	1.16300000	3.82560000	5.95270000	0.060000
432	1.37000000	3.65750000	5.69110000	0.060000
433	0.00000000	4.12650000	6.84310000	0.060000
434	0.33230000	4.03770000	6.69580000	0.060000
435	0.64010000	3.92830000	6.51430000	0.060000
436	0.91850000	3.79970000	6.30100000	0.060000
437	1.16300000	3.65410000	6.05950000	0.060000
438	1.37000000	3.49340000	5.79320000	0.060000
439	0.00000000	3.92940000	6.95820000	0.060000
440	0.33230000	3.84490000	6.80840000	0.060000
441	0.64010000	3.74060000	6.62370000	0.060000
442	0.91850000	3.61820000	6.40700000	0.060000
443	1.16300000	3.47950000	6.16140000	0.060000
444	1.37000000	3.32660000	5.89060000	0.060000
445	0.00000000	3.72910000	7.06750000	0.060000
446	0.33230000	3.64880000	6.91540000	0.060000
447	0.64010000	3.54990000	6.72790000	0.060000
448	0.91850000	3.43380000	6.50770000	0.060000
449	1.16300000	3.30220000	6.25820000	0.060000
450	1.37000000	3.15700000	5.98320000	0.060000
451	0.00000000	3.52580000	7.17110000	0.060000
452	0.33230000	3.44990000	7.01680000	0.060000

453	0.64010000	3.35640000	6.82650000	0.060000
454	0.91850000	3.24650000	6.60300000	0.060000
455	1.16300000	3.12210000	6.35000000	0.060000
456	1.37000000	2.98490000	6.07090000	0.060000
457	0.00000000	3.31960000	7.26890000	0.060000
458	0.33230000	3.24820000	7.11240000	0.060000
459	0.64010000	3.16010000	6.91960000	0.060000
460	0.91850000	3.05670000	6.69310000	0.060000
461	1.16300000	2.93950000	6.43660000	0.060000
462	1.37000000	2.81030000	6.15370000	0.060000
463	0.00000000	3.11070000	7.36070000	0.060000
464	0.33230000	3.04380000	7.20230000	0.060000
465	0.64010000	2.96120000	7.00700000	0.060000
466	0.91850000	2.86430000	6.77760000	0.060000
467	1.16300000	2.75450000	6.51790000	0.060000
468	1.37000000	2.63340000	6.23140000	0.060000
469	0.00000000	2.89920000	7.44650000	0.060000
470	0.33230000	2.83680000	7.28630000	0.060000
471	0.64010000	2.75990000	7.08870000	0.060000
472	0.91850000	2.66960000	6.85670000	0.060000
473	1.16300000	2.56720000	6.59380000	0.060000
474	1.37000000	2.45440000	6.30410000	0.060000
475	0.00000000	2.68540000	7.52620000	0.060000
476	0.33230000	2.62760000	7.36430000	0.060000
477	0.64010000	2.55640000	7.16460000	0.060000
478	0.91850000	2.47260000	6.93010000	0.060000
479	1.16300000	2.37790000	6.66450000	0.060000
480	1.37000000	2.27340000	6.37160000	0.060000
481	0.00000000	2.46940000	7.59990000	0.060000
482	0.33230000	2.41620000	7.43630000	0.060000
483	0.64010000	2.35070000	7.23460000	0.060000
484	0.91850000	2.27370000	6.99790000	0.060000
485	1.16300000	2.18660000	6.72960000	0.060000
486	1.37000000	2.09050000	6.43390000	0.060000
487	0.00000000	2.25130000	7.66740000	0.060000
488	0.33230000	2.20290000	7.50230000	0.060000
489	0.64010000	2.14310000	7.29890000	0.060000
490	0.91850000	2.07300000	7.05990000	0.060000
491	1.16300000	1.99350000	6.78940000	0.060000
492	1.37000000	1.90600000	6.49100000	0.060000
493	0.00000000	2.03140000	7.72850000	0.060000
494	0.33230000	1.98780000	7.56220000	0.060000
495	0.64010000	1.93390000	7.35710000	0.060000
496	0.91850000	1.87050000	7.11630000	0.060000
497	1.16300000	1.79880000	6.84350000	0.060000
498	1.37000000	1.71980000	6.54280000	0.060000

499	0.00000000	1.81000000	7.78340000	0.060000
500	0.33230000	1.77100000	7.61580000	0.060000
501	0.64010000	1.72300000	7.40930000	0.060000
502	0.91850000	1.66660000	7.16670000	0.060000
503	1.16300000	1.60270000	6.89210000	0.060000
504	1.37000000	1.53220000	6.58920000	0.060000
505	0.00000000	1.58690000	7.83190000	0.060000
506	0.33230000	1.55280000	7.66330000	0.060000
507	0.64010000	1.51070000	7.45550000	0.060000
508	0.91850000	1.46130000	7.21140000	0.060000
509	1.16300000	1.40530000	6.93500000	0.060000
510	1.37000000	1.34350000	6.63020000	0.060000
511	0.00000000	1.36270000	7.87400000	0.060000
512	0.33230000	1.33330000	7.70450000	0.060000
513	0.64010000	1.29720000	7.49560000	0.060000
514	0.91850000	1.25470000	7.25020000	0.060000
515	1.16300000	1.20660000	6.97230000	0.060000
516	1.37000000	1.15360000	6.66590000	0.060000
517	0.00000000	1.13720000	7.90970000	0.060000
518	0.33230000	1.11270000	7.73940000	0.060000
519	0.64010000	1.08260000	7.52960000	0.060000
520	0.91850000	1.04710000	7.28310000	0.060000
521	1.16300000	1.00700000	7.00400000	0.060000
522	1.37000000	0.96276000	6.69610000	0.060000
523	0.00000000	0.91093000	7.93890000	0.060000
524	0.33230000	0.89133000	7.76800000	0.060000
525	0.64010000	0.86713000	7.55740000	0.060000
526	0.91850000	0.83873000	7.31000000	0.060000
527	1.16300000	0.80664000	7.02990000	0.060000
528	1.37000000	0.77121000	6.72090000	0.060000
529	0.00000000	0.68386000	7.96170000	0.060000
530	0.33230000	0.66913000	7.79040000	0.060000
531	0.64010000	0.65097000	7.57910000	0.060000
532	0.91850000	0.62968000	7.33110000	0.060000
533	1.16300000	0.60554000	7.05000000	0.060000
534	1.37000000	0.57892000	6.74020000	0.060000
535	0.00000000	0.45619000	7.97790000	0.060000
536	0.33230000	0.44639000	7.80630000	0.060000
537	0.64010000	0.43430000	7.59460000	0.060000
538	0.91850000	0.42007000	7.34610000	0.060000
539	1.16300000	0.40397000	7.06440000	0.060000
540	1.37000000	0.38623000	6.75400000	0.060000
541	0.00000000	0.22819000	7.98770000	0.060000
542	0.33230000	0.22327000	7.81580000	0.060000
543	0.64010000	0.21726000	7.60390000	0.060000
544	0.91850000	0.21016000	7.35500000	0.060000

545	1.16300000	0.20205000	7.07310000	0.060000
546	1.37000000	0.19314000	6.76230000	0.060000
547	0.00000000	0.00001495	7.99100000	0.060000
548	0.33230000	0.00004901	7.81900000	0.060000
549	0.64010000	-0.00001551	7.60700000	0.060000
550	0.91850000	0.00004126	7.35800000	0.060000
551	1.16300000	0.00000483	7.07600000	0.060000
552	1.37000000	0.00001577	6.76490000	0.060000
553	0.00000000	-0.22820000	7.98780000	0.060000
554	0.33230000	-0.22328000	7.81580000	0.060000
555	0.64010000	-0.21724000	7.60390000	0.060000
556	0.91850000	-0.21009000	7.35500000	0.060000
557	1.16300000	-0.20203000	7.07310000	0.060000
558	1.37000000	-0.19321000	6.76220000	0.060000
559	0.00000000	-0.45618000	7.97800000	0.060000
560	0.33230000	-0.44634000	7.80630000	0.060000
561	0.64010000	-0.43426000	7.59460000	0.060000
562	0.91850000	-0.42007000	7.34600000	0.060000
563	1.16300000	-0.40398000	7.06440000	0.060000
564	1.37000000	-0.38621000	6.75390000	0.060000
565	0.00000000	-0.68384000	7.96170000	0.060000
566	0.33230000	-0.66909000	7.79030000	0.060000
567	0.64010000	-0.65095000	7.57910000	0.060000
568	0.91850000	-0.62964000	7.33100000	0.060000
569	1.16300000	-0.60549000	7.05010000	0.060000
570	1.37000000	-0.57888000	6.74020000	0.060000
571	0.00000000	-0.91084000	7.93890000	0.060000
572	0.33230000	-0.89130000	7.76810000	0.060000
573	0.64010000	-0.86716000	7.55740000	0.060000
574	0.91850000	-0.83870000	7.31000000	0.060000
575	1.16300000	-0.80657000	7.02980000	0.060000
576	1.37000000	-0.77110000	6.72090000	0.060000
577	0.00000000	-1.13720000	7.90970000	0.060000
578	0.33230000	-1.11280000	7.73950000	0.060000
579	0.64010000	-1.08250000	7.52960000	0.060000
580	0.91850000	-1.04710000	7.28310000	0.060000
581	1.16300000	-1.00700000	7.00400000	0.060000
582	1.37000000	-0.96279000	6.69610000	0.060000
583	0.00000000	-1.36270000	7.87400000	0.060000
584	0.33230000	-1.33330000	7.70450000	0.060000
585	0.64010000	-1.29710000	7.49550000	0.060000
586	0.91850000	-1.25460000	7.25030000	0.060000
587	1.16300000	-1.20660000	6.97230000	0.060000
588	1.37000000	-1.15360000	6.66590000	0.060000
589	0.00000000	-1.58690000	7.83180000	0.060000
590	0.33230000	-1.55280000	7.66330000	0.060000

591	0.64010000	-1.51070000	7.45550000	0.060000
592	0.91850000	-1.46120000	7.21140000	0.060000
593	1.16300000	-1.40520000	6.93510000	0.060000
594	1.37000000	-1.34340000	6.63030000	0.060000
595	0.00000000	-1.81000000	7.78330000	0.060000
596	0.33230000	-1.77100000	7.61580000	0.060000
597	0.64010000	-1.72300000	7.40930000	0.060000
598	0.91850000	-1.66660000	7.16680000	0.060000
599	1.16300000	-1.60270000	6.89210000	0.060000
600	1.37000000	-1.53230000	6.58920000	0.060000
601	0.00000000	-2.03140000	7.72850000	0.060000
602	0.33230000	-1.98780000	7.56220000	0.060000
603	0.64010000	-1.93380000	7.35710000	0.060000
604	0.91850000	-1.87060000	7.11630000	0.060000
605	1.16300000	-1.79880000	6.84360000	0.060000
606	1.37000000	-1.71970000	6.54280000	0.060000
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609	0.64010000	-2.14310000	7.29890000	0.060000
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611	1.16300000	-1.99350000	6.78940000	0.060000
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614	0.33230000	-2.41620000	7.43630000	0.060000
615	0.64010000	-2.35070000	7.23470000	0.060000
616	0.91850000	-2.27370000	6.99790000	0.060000
617	1.16300000	-2.18660000	6.72970000	0.060000
618	1.37000000	-2.09050000	6.43390000	0.060000
619	0.00000000	-2.68530000	7.52630000	0.060000
620	0.33230000	-2.62750000	7.36430000	0.060000
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622	0.91850000	-2.47270000	6.93010000	0.060000
623	1.16300000	-2.37790000	6.66450000	0.060000
624	1.37000000	-2.27340000	6.37160000	0.060000
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627	0.64010000	-2.75990000	7.08870000	0.060000
628	0.91850000	-2.66950000	6.85670000	0.060000
629	1.16300000	-2.56720000	6.59390000	0.060000
630	1.37000000	-2.45440000	6.30410000	0.060000
631	0.00000000	-3.11060000	7.36070000	0.060000
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633	0.64010000	-2.96120000	7.00700000	0.060000
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635	1.16300000	-2.75450000	6.51790000	0.060000
636	1.37000000	-2.63340000	6.23140000	0.060000

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719	1.16300000	-5.07440000	4.93150000	0.060000
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787	0.00000000	6.03920000	5.23300000	0.125000
788	0.33230000	5.90920000	5.12030000	0.125000
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647	836	746	747	837
648	848	758	759	849
649	860	770	771	861
650	789	909	910	790
651	801	921	922	802
652	813	933	934	814
653	825	735	736	826
654	837	747	748	838
655	849	759	760	850
656	861	771	772	862
657	790	910	911	791
658	802	922	923	803
659	814	934	935	815
660	826	736	737	827
661	838	748	749	839
662	850	760	761	851
663	862	772	773	863
664	791	911	912	792
665	803	923	924	804
666	815	935	936	816
667	827	737	738	828
668	839	749	750	840
669	851	761	762	852
670	863	773	774	864
671	781	787	788	782
672	793	799	800	794
673	805	811	812	806
674	817	823	824	818
675	829	835	836	830
676	841	847	848	842
677	853	859	860	854
678	782	788	789	783
679	794	800	801	795
680	806	812	813	807
681	818	824	825	819
682	830	836	837	831
683	842	848	849	843
684	854	860	861	855
685	783	789	790	784
686	795	801	802	796
687	807	813	814	808
688	819	825	826	820
689	831	837	838	832
690	843	849	850	844
691	855	861	862	856

692	784	790	791	785
693	796	802	803	797
694	808	814	815	809
695	820	826	827	821
696	832	838	839	833
697	844	850	851	845
698	856	862	863	857
699	785	791	792	786
700	797	803	804	798
701	809	815	816	810
702	821	827	828	822
703	833	839	840	834
704	845	851	852	846
705	857	863	864	858
706	865	781	782	866
707	871	793	794	872
708	877	805	806	878
709	883	817	818	884
710	889	829	830	890
711	895	841	842	896
712	901	853	854	902
713	866	782	783	867
714	872	794	795	873
715	878	806	807	879
716	884	818	819	885
717	890	830	831	891
718	896	842	843	897
719	902	854	855	903
720	867	783	784	868
721	873	795	796	874
722	879	807	808	880
723	885	819	820	886
724	891	831	832	892
725	897	843	844	898
726	903	855	856	904
727	868	784	785	869
728	874	796	797	875
729	880	808	809	881
730	886	820	821	887
731	892	832	833	893
732	898	844	845	899
733	904	856	857	905
734	869	785	786	870
735	875	797	798	876
736	881	809	810	882
737	887	821	822	888

```
  738  893  833  834  894
  739  899  845  846  900
  740  905  857  858  906
C The Hex turn around vane is supported at alternate bays
C 4 nodes for the six bay model
*BOUNDARY
      783    1     0.00
      783    2     0.00
      783    3     0.00
      783    4     0.00
      783    5     0.00
      783    6     0.00
      807    1     0.00
      807    2     0.00
      807    3     0.00
      807    4     0.00
      807    5     0.00
      807    6     0.00
      831    1     0.00
      831    2     0.00
      831    3     0.00
      831    4     0.00
      831    5     0.00
      831    6     0.00
      855    1     0.00
      855    2     0.00
      855    3     0.00
      855    4     0.00
      855    5     0.00
      855    6     0.00
C  END OF FIXED NODES
*DUPLICATENODES
C======================================
C INTERFACE OF INNER VANES AND SPLITTERS
C======================================
C  MASTER   SLAVE
   1      913
   2      914
   3      915
   4      916
   5      917
   6      918
C
  61      925
  62      926
  63      927
```

```
   64     928
   65     929
   66     930
C
   121    937
   122    938
   123    939
   124    940
   125    941
   126    942
C
   181    739
   182    740
   183    741
   184    742
   185    743
   186    744
C
   241    751
   242    752
   243    753
   244    754
   245    755
   246    756
C
   301    763
   302    764
   303    765
   304    766
   305    767
   306    768
C
   361    775
   362    776
   363    777
   364    778
   365    779
   366    780
C=========================================
C INTERFACE OF OUTER VANES AND SPLITTERS
C=========================================
C  MASTER   SLAVE
C
   367    787
   368    788
   369    789
```

```
  370   790
  371   791
  372   792
C
  427   799
  428   800
  429   801
  430   802
  431   803
  432   804
C
  487   811
  488   812
  489   813
  490   814
  491   815
  492   816
C
  547   823
  548   824
  549   825
  550   826
  551   827
  552   828
C
  607   835
  608   836
  609   837
  610   838
  611   839
  612   840
C
  667   847
  668   848
  669   849
  670   850
  671   851
  672   852
C
  727   859
  728   860
  729   861
  730   862
  731   863
  732   864
C END OF DUPLICATED NODES
```

```
*PROPERTIES 75
C
C  E     = 25.5E+6  Modulus of Elasticity
C  PR    = 0.33     Poison's Ratio
C  ALPHA = 0.0      Coefficient of thermal expension
C  DEN   = 0.305    WEIGHT/VOLUME = 7.89337474E-4 MASS/VOLUME
C
 1 942  0.0 25.5E+6  0.33  0.0 7.89337474E-4
C 50 iterations for the Subspace modal extraction phase
*ITER 0 11
 50
C Low model damping one half of one percent
*DAMPING 2
 1  50 0.005
*PSD   1
C Inner Vane pai=   3.1415927410126 frequency is in radians/sec
C nodal forces corresponding to unit pressure
 0.31415927E+02 0.12300051E-12
 0.15854236E+03 0.90517143E-10
 0.28566880E+03 0.52999231E-09
 0.41279523E+03 0.80679458E-09
 0.53992167E+03 0.10094673E-08
 0.66704810E+03 0.12478097E-08
 0.79417580E+03 0.15437727E-08
 0.92130349E+03 0.19053074E-08
 0.10484249E+04 0.23390524E-08
 0.11755526E+04 0.28523111E-08
 0.13026803E+04 0.34536303E-08
 0.14298080E+04 0.41527502E-08
 0.15569357E+04 0.49608594E-08
 0.16840571E+04 0.58905630E-08
 0.18111848E+04 0.69560735E-08
 0.19383125E+04 0.81732905E-08
 0.20654401E+04 0.95599438E-08
 0.21925616E+04 0.11135785E-07
 0.23196892E+04 0.12922744E-07
 0.24468169E+04 0.14945110E-07
 0.25739446E+04 0.17229795E-07
 0.27010723E+04 0.19806514E-07
 0.28281937E+04 0.22708386E-07
 0.29553214E+04 0.25971380E-07
 0.30824491E+04 0.29635764E-07
 0.32095768E+04 0.33745622E-07
 0.33367045E+04 0.38349815E-07
 0.34638259E+04 0.43501979E-07
```

0.35909536E+04	0.49261477E-07
0.37180813E+04	0.55693247E-07
0.38452090E+04	0.62869384E-07
0.39723367E+04	0.70868670E-07
0.40994581E+04	0.79778323E-07
0.42265858E+04	0.89693994E-07
0.43537135E+04	0.10072104E-06
0.44808412E+04	0.11297534E-06
0.46079689E+04	0.12658420E-06
0.47350903E+04	0.14168721E-06
0.48622180E+04	0.15843810E-06
0.49893456E+04	0.17700576E-06
0.51164733E+04	0.19757335E-06
0.52436010E+04	0.22034365E-06
0.53707224E+04	0.24553946E-06
0.54978501E+04	0.27339954E-06
0.56249778E+04	0.30418965E-06
0.57521055E+04	0.33819629E-06
0.58792332E+04	0.37573298E-06
0.60063546E+04	0.41713873E-06
0.61334823E+04	0.46277800E-06
0.62606100E+04	0.51305027E-06
0.63877377E+04	0.56838048E-06
0.65148465E+04	0.62922701E-06
0.66420182E+04	0.69607845E-06
0.67691270E+04	0.76945365E-06
0.68962359E+04	0.84990170E-06
0.70233447E+04	0.93800032E-06
0.71505164E+04	0.10343527E-05
0.72776252E+04	0.11395828E-05
0.74047341E+04	0.12543271E-05
0.75318429E+04	0.13792335E-05
0.76590146E+04	0.15149497E-05
0.77861234E+04	0.16621028E-05
0.79132323E+04	0.18213214E-05
0.80404040E+04	0.19931610E-05
0.81675128E+04	0.21781467E-05
0.82946217E+04	0.23767084E-05
0.84217305E+04	0.25892121E-05
0.85489022E+04	0.28158647E-05
0.86760110E+04	0.30567934E-05
0.88031199E+04	0.33119506E-05
0.89302915E+04	0.35810975E-05
0.90574004E+04	0.38638363E-05
0.91845092E+04	0.41595780E-05
0.93116181E+04	0.44675587E-05

0.94387897E+04	0.47867758E-05
0.95658986E+04	0.51160992E-05
0.96930074E+04	0.54542079E-05
0.98201791E+04	0.57996696E-05
0.99472879E+04	0.61509405E-05
0.10074397E+05	0.65064130E-05
0.10201506E+05	0.68644798E-05
0.10328677E+05	0.72235334E-05
0.10455786E+05	0.75820299E-05
0.10582895E+05	0.79385528E-05
0.10710004E+05	0.82917972E-05
0.10837175E+05	0.86406330E-05
0.10964284E+05	0.89841212E-05
0.11091393E+05	0.93215297E-05
0.11218565E+05	0.96523014E-05
0.11345674E+05	0.99761180E-05
0.11472783E+05	0.10292836E-04
0.11599891E+05	0.10602520E-04
0.11727063E+05	0.10905376E-04
0.11854172E+05	0.11201770E-04
0.11981281E+05	0.11492196E-04
0.12108452E+05	0.11777274E-04
0.12235561E+05	0.12057705E-04
0.12362670E+05	0.12334221E-04
0.12489779E+05	0.12607665E-04
0.12616951E+05	0.12878881E-04
0.12744059E+05	0.13148728E-04
0.12871168E+05	0.13418114E-04
0.12998277E+05	0.13687898E-04
0.13125449E+05	0.13958986E-04
0.13252558E+05	0.14232208E-04
0.13379666E+05	0.14508437E-04
0.13506838E+05	0.14788470E-04
0.13633947E+05	0.15073119E-04
0.13761056E+05	0.15363147E-04
0.13888165E+05	0.15659318E-04
0.14015336E+05	0.15962285E-04
0.14142445E+05	0.16272797E-04
0.14269554E+05	0.16591584E-04
0.14396726E+05	0.16918966E-04
0.14523835E+05	0.17255897E-04
0.14650943E+05	0.17602695E-04
0.14778052E+05	0.17959998E-04
0.14905224E+05	0.18328124E-04
0.15032333E+05	0.18707708E-04
0.15159442E+05	0.19099229E-04

0.15286613E+05	0.19503005E-04
0.15413722E+05	0.19919196E-04
0.15540831E+05	0.20348118E-04
0.15667940E+05	0.20790250E-04
0.15795111E+05	0.21245593E-04
0.15922220E+05	0.21714304E-04
0.16049329E+05	0.22196544E-04
0.16176438E+05	0.22691993E-04
0.16303610E+05	0.23200811E-04
0.16430719E+05	0.23722839E-04
0.16557827E+05	0.24257600E-04
0.16684999E+05	0.24804934E-04
0.16812108E+05	0.25364363E-04
0.16939217E+05	0.25935252E-04
0.17066326E+05	0.26516804E-04
0.17193497E+05	0.27108224E-04
0.17320606E+05	0.27708716E-04
0.17447715E+05	0.28317165E-04
0.17574887E+05	0.28932299E-04
0.17701995E+05	0.29552685E-04
0.17829104E+05	0.30177050E-04
0.17956213E+05	0.30803643E-04
0.18083385E+05	0.31430713E-04
0.18210494E+05	0.32056510E-04
0.18337602E+05	0.32678965E-04
0.18464774E+05	0.33296009E-04
0.18591883E+05	0.33905572E-04
0.18718992E+05	0.34505427E-04
0.18846101E+05	0.35093346E-04
0.18973272E+05	0.35666940E-04
0.19100381E+05	0.36224301E-04
0.19227490E+05	0.36762881E-04
0.19354599E+05	0.37280771E-04
0.19481771E+05	0.37775743E-04
0.19608879E+05	0.38246046E-04
0.19735988E+05	0.38689929E-04
0.19863160E+05	0.39105801E-04
0.19990269E+05	0.39492070E-04
0.20117378E+05	0.39847940E-04
0.20244486E+05	0.40172139E-04
0.20371658E+05	0.40464188E-04
0.20498767E+05	0.40723770E-04
0.20625876E+05	0.40950566E-04
0.20753047E+05	0.41144735E-04
0.20880156E+05	0.41306595E-04
0.21007265E+05	0.41436943E-04

0.21134374E+05	0.41536256E-04
0.21261546E+05	0.41605966E-04
0.21388655E+05	0.41647028E-04
0.21515763E+05	0.41660874E-04
0.21642872E+05	0.41649256E-04
0.21770044E+05	0.41613605E-04
0.21897153E+05	0.41555991E-04
0.22024262E+05	0.41477846E-04
0.22151433E+05	0.41381239E-04
0.22278542E+05	0.41268239E-04
0.22405651E+05	0.41140597E-04
0.22532760E+05	0.41000222E-04
0.22659931E+05	0.40849184E-04
0.22787040E+05	0.40689074E-04
0.22914149E+05	0.40521961E-04
0.23041321E+05	0.40349278E-04
0.23168430E+05	0.40172935E-04
0.23295538E+05	0.39994363E-04
0.23422647E+05	0.39815154E-04
0.23549819E+05	0.39636742E-04
0.23676928E+05	0.39460398E-04
0.23804037E+05	0.39287556E-04
0.23931208E+05	0.39119011E-04
0.24058317E+05	0.38956354E-04
0.24185426E+05	0.38800064E-04
0.24312535E+05	0.38651413E-04
0.24439707E+05	0.38511198E-04
0.24566815E+05	0.38380213E-04
0.24693924E+05	0.38259097E-04
0.24821033E+05	0.38148484E-04
0.24948205E+05	0.38049012E-04
0.25075314E+05	0.37961159E-04
0.25202422E+05	0.37885560E-04
0.25329594E+05	0.37822535E-04
0.25456703E+05	0.37772401E-04
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0.25838092E+05	0.37703168E-04
0.25965201E+05	0.37707943E-04
0.26092310E+05	0.37727042E-04
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0.26473699E+05	0.37870758E-04
0.26600808E+05	0.37947789E-04
0.26727980E+05	0.38039463E-04
0.26855089E+05	0.38145778E-04

0.26982198E+05	0.38266418E-04
0.27109369E+05	0.38401222E-04
0.27236478E+05	0.38550350E-04
0.27363587E+05	0.38713325E-04
0.27490696E+05	0.38889828E-04
0.27617867E+05	0.39079699E-04
0.27744976E+05	0.39282304E-04
0.27872085E+05	0.39497322E-04
0.27999194E+05	0.39724277E-04
0.28126366E+05	0.39962214E-04
0.28253474E+05	0.40210654E-04
0.28380583E+05	0.40468804E-04
0.28507755E+05	0.40735707E-04
0.28634864E+05	0.41010249E-04
0.28761973E+05	0.41291316E-04
0.28889082E+05	0.41577954E-04
0.29016253E+05	0.41868412E-04
0.29143362E+05	0.42161576E-04
0.29270471E+05	0.42455535E-04
0.29397643E+05	0.42748857E-04
0.29524751E+05	0.43039474E-04
0.29651860E+05	0.43325635E-04
0.29778969E+05	0.43604952E-04
0.29906141E+05	0.43875515E-04
0.30033250E+05	0.44135097E-04
0.30160358E+05	0.44380991E-04
0.30287467E+05	0.44611129E-04
0.30414639E+05	0.44822965E-04
0.30541748E+05	0.45013791E-04
0.30668857E+05	0.45181381E-04
0.30796028E+05	0.45323348E-04
0.30923137E+05	0.45437143E-04
0.31050246E+05	0.45520541E-04
0.31177355E+05	0.45571470E-04
0.31304527E+05	0.45588181E-04
0.31431635E+05	0.45568605E-04
0.31558744E+05	0.45511469E-04
0.31685916E+05	0.45415498E-04
0.31813025E+05	0.45279898E-04
0.31940134E+05	0.45104191E-04
0.32067242E+05	0.44887900E-04
0.32194414E+05	0.44631183E-04
0.32321523E+05	0.44334836E-04
0.32448632E+05	0.43999338E-04
0.32575803E+05	0.43625960E-04
0.32702912E+05	0.43216295E-04

0.32830021E+05	0.42772094E-04
0.32957130E+05	0.42295584E-04
0.33084302E+05	0.41788835E-04
0.33211410E+05	0.41254392E-04
0.33338519E+05	0.40695122E-04
0.33465628E+05	0.40113570E-04
0.33592800E+05	0.39512760E-04
0.33719909E+05	0.38895398E-04
0.33847018E+05	0.38264667E-04
0.33974189E+05	0.37623273E-04
0.34101298E+05	0.36974080E-04
0.34228407E+05	0.36319634E-04
0.34355516E+05	0.35662643E-04
0.34482687E+05	0.35005651E-04
0.34609796E+05	0.34350729E-04
0.34736905E+05	0.33700103E-04
0.34864077E+05	0.33055844E-04
0.34991186E+05	0.32419543E-04
0.35118294E+05	0.31792950E-04
0.35245403E+05	0.31177498E-04
0.35372575E+05	0.30574300E-04
0.35499684E+05	0.29984631E-04
0.35626793E+05	0.29409286E-04
0.35753901E+05	0.28849061E-04
0.35881073E+05	0.28304751E-04
0.36008182E+05	0.27776675E-04
0.36135291E+05	0.27265310E-04
0.36262463E+05	0.26770816E-04
0.36389571E+05	0.26293510E-04
0.36516680E+05	0.25833393E-04
0.36643789E+05	0.25390624E-04
0.36770961E+05	0.24964725E-04
0.36898070E+05	0.24555856E-04
0.37025178E+05	0.24163539E-04
0.37152350E+05	0.23787615E-04
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0.37406568E+05	0.23083196E-04
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FORCES

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175	4	-.82863E-06
175	5	-.19504E-02
175	6	0.56083E-04
176	1	0.39585E-01
176	2	0.28872E-02
176	3	0.10077E+00
176	4	-.31222E-05
176	5	-.12520E-03
176	6	0.49594E-05
177	1	0.54282E-01
177	2	0.29305E-02
177	3	0.10241E+00
177	4	-.67180E-06
177	5	-.11751E-03
177	6	0.35795E-05
178	1	0.69682E-01
178	2	0.28940E-02
178	3	0.10138E+00
178	4	-.10501E-05
178	5	-.12149E-03
178	6	0.41007E-05
179	1	0.79008E-01
179	2	0.25993E-02
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179	4	-.30285E-06
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180	2	0.93526E-03
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 182    1  0.19802E-01
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 183    1  0.27144E-01
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 183    3  0.51230E-01
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 183    5  -.57995E-04
 183    6  -.92789E-03
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 184    2  0.72346E-03
 184    3  0.50722E-01
 184    4  0.17049E-02
 184    5  -.61296E-04
 184    6  -.11711E-02
 185    1  0.39512E-01
 185    2  0.65036E-03
 185    3  0.45530E-01
 185    4  0.14964E-02
 185    5  0.17099E-03
 185    6  -.13018E-02
 186    1  0.16075E-01
 186    2  0.23162E-03
 186    3  0.16356E-01
 186    4  0.52624E-03
 186    5  0.90911E-03
 186    6  -.53006E-03
*FREQ 0 4
C Varying discretization strategy based frequency range of interest
C to obtain accurate results with less computational effort
 10  0.31415927E+02   3500.00
 50  3500.0          20000.0
 300  20000.0         32000.0
 10  32000.00        0.62831855E+05
*PSD   2
C Outer vane  pai=   3.1415927410126
 0.31415927E+02  0.81689615E-12
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0.66704810E+03	0.10941838E-07
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0.92130349E+03	0.12765356E-07
0.10484249E+04	0.14012637E-07
0.11755526E+04	0.15524832E-07
0.13026803E+04	0.17329108E-07
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0.15569357E+04	0.21947466E-07
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0.46051163E+05	0.22477134E-06
0.46178272E+05	0.21260553E-06
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0.46559661E+05	0.18034005E-06
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0.46813942E+05	0.16190991E-06

0.46941050E+05	0.15350064E-06
0.47068159E+05	0.14558252E-06
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0.47322440E+05	0.13109545E-06
0.47449549E+05	0.12446967E-06
0.47576657E+05	0.11822108E-06
0.47703829E+05	0.11232583E-06
0.47830938E+05	0.10676209E-06
0.47958047E+05	0.10150918E-06
0.48085218E+05	0.96547524E-07
0.48212327E+05	0.91859615E-07
0.48339436E+05	0.87428582E-07
0.48466545E+05	0.83238829E-07
0.48593717E+05	0.79275712E-07
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0.62450465E+05	0.14717407E-08
0.62577574E+05	0.14307695E-08
0.62704746E+05	0.13910842E-08
0.62831855E+05	0.13526419E-08

FORCES

487	1	0.10372E-01
487	2	0.53657E-02
487	3	0.19311E-01
487	4	-.76647E-03
487	5	-.12506E-02
487	6	0.75916E-03
488	1	0.23564E-01
488	2	0.10519E-01
488	3	0.37817E-01
488	4	-.14612E-02
488	5	0.22513E-03

488	6	0.84949E-03
489	1	0.28765E-01
489	2	0.98042E-02
489	3	0.35223E-01
489	4	-.13233E-02
489	5	0.27665E-03
489	6	0.10043E-02
490	1	0.33446E-01
490	2	0.88318E-02
490	3	0.31729E-01
490	4	-.11536E-02
490	5	0.32306E-03
490	6	0.11278E-02
491	1	0.39942E-01
491	2	0.80897E-02
491	3	0.29079E-01
491	4	-.10202E-02
491	5	0.13300E-03
491	6	0.13657E-02
492	1	0.25451E-01
492	2	0.45366E-02
492	3	0.16327E-01
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492	6	0.28198E-03
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493	3	0.38753E-01
493	4	0.10425E-05
493	5	-.27334E-02
493	6	0.71796E-03
494	1	0.47134E-01
494	2	0.19955E-01
494	3	0.75927E-01
494	4	-.89862E-06
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494	6	0.12694E-04
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495	3	0.70722E-01
495	4	-.13743E-05
495	5	-.32086E-04
495	6	0.95894E-05
496	1	0.66880E-01
496	2	0.16738E-01
496	3	0.63691E-01

496	4	0.17419E-05
496	5	-.16960E-04
496	6	0.26395E-05
497	1	0.79871E-01
497	2	0.15339E-01
497	3	0.58368E-01
497	4	0.67622E-06
497	5	-.49557E-03
497	6	0.12937E-03
498	1	0.50901E-01
498	2	0.86126E-02
498	3	0.32773E-01
498	4	0.21000E-07
498	5	0.35540E-02
498	6	-.93396E-03
499	1	0.20747E-01
499	2	0.90803E-02
499	3	0.39034E-01
499	4	-.10788E-05
499	5	-.27538E-02
499	6	0.64128E-03
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500	2	0.17783E-01
500	3	0.76476E-01
500	4	-.17978E-06
500	5	-.45965E-04
500	6	0.10242E-04
501	1	0.57547E-01
501	2	0.16560E-01
501	3	0.71240E-01
501	4	-.13124E-07
501	5	-.33263E-04
501	6	0.80417E-05
502	1	0.66865E-01
502	2	0.14908E-01
502	3	0.64130E-01
502	4	-.94528E-06
502	5	-.13965E-04
502	6	0.39492E-05
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503	3	0.58767E-01
503	4	0.42246E-06
503	5	-.50119E-03
503	6	0.11643E-03
504	1	0.50891E-01

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504	3	0.32995E-01
504	4	0.81632E-06
504	5	0.35791E-02
504	6	-.83338E-03
505	1	0.20748E-01
505	2	0.79558E-02
505	3	0.39279E-01
505	4	0.11585E-05
505	5	-.27710E-02
505	6	0.56059E-03
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506	2	0.15590E-01
506	3	0.76951E-01
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506	5	-.46518E-04
506	6	0.96818E-05
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508	3	0.64552E-01
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511	1	0.20748E-01
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511	3	0.39491E-01
511	4	-.12987E-05
511	5	-.27858E-02

511	6	0.48269E-03
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512	5	-.46565E-04
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513	2	0.12468E-01
513	3	0.72071E-01
513	4	-.50749E-06
513	5	-.34090E-04
513	6	0.67208E-05
514	1	0.66907E-01
514	2	0.11236E-01
514	3	0.64912E-01
514	4	0.29477E-06
514	5	-.16255E-04
514	6	0.24791E-05
515	1	0.79902E-01
515	2	0.10300E-01
515	3	0.59482E-01
515	4	0.88406E-06
515	5	-.50528E-03
515	6	0.86688E-04
516	1	0.50905E-01
516	2	0.57837E-02
516	3	0.33386E-01
516	4	-.21004E-06
516	5	0.36216E-02
516	6	-.62700E-03
517	1	0.20749E-01
517	2	0.56989E-02
517	3	0.39670E-01
517	4	0.90516E-06
517	5	-.27986E-02
517	6	0.40156E-03
518	1	0.47131E-01
518	2	0.11164E-01
518	3	0.77706E-01
518	4	0.19401E-05
518	5	-.46329E-04
518	6	0.55197E-05
519	1	0.57539E-01
519	2	0.10402E-01
519	3	0.72395E-01

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519	6	0.49971E-05
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520	5	-.15368E-04
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521	6	0.72547E-04
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522	2	0.48289E-02
522	3	0.33531E-01
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522	5	0.36388E-02
522	6	-.52385E-03
523	1	0.20742E-01
523	2	0.45664E-02
523	3	0.39811E-01
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523	5	-.28082E-02
523	6	0.32225E-03
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524	5	-.46844E-04
524	6	0.68228E-05
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525	2	0.83438E-02
525	3	0.72657E-01
525	4	-.39987E-06
525	5	-.34163E-04
525	6	0.33645E-05
526	1	0.66869E-01
526	2	0.75117E-02
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526	4	0.48290E-06
526	5	-.15088E-04
526	6	0.21583E-05
527	1	0.79874E-01

527	2	0.68819E-02
527	3	0.59951E-01
527	4	-.13994E-05
527	5	-.51167E-03
527	6	0.59282E-04
528	1	0.50905E-01
528	2	0.38568E-02
528	3	0.33660E-01
528	4	-.34513E-06
528	5	0.36521E-02
528	6	-.41809E-03
529	1	0.20737E-01
529	2	0.34245E-02
529	3	0.39930E-01
529	4	-.34603E-06
529	5	-.28163E-02
529	6	0.24156E-03
530	1	0.47134E-01
530	2	0.67209E-02
530	3	0.78226E-01
530	4	0.57217E-06
530	5	-.48238E-04
530	6	0.46081E-05
531	1	0.57531E-01
531	2	0.62674E-02
531	3	0.72864E-01
531	4	0.81243E-07
531	5	-.32276E-04
531	6	0.22418E-05
532	1	0.66882E-01
532	2	0.56479E-02
532	3	0.65614E-01
532	4	0.18607E-06
532	5	-.18820E-04
532	6	0.23196E-05
533	1	0.79894E-01
533	2	0.51693E-02
533	3	0.60135E-01
533	4	-.64477E-06
533	5	-.50982E-03
533	6	0.42970E-04
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534	2	0.28924E-02
534	3	0.33758E-01
534	4	0.74120E-06
534	5	0.36615E-02

534	6	-.31498E-03
535	1	0.20735E-01
535	2	0.22832E-02
535	3	0.40014E-01
535	4	0.14011E-06
535	5	-.28217E-02
535	6	0.16098E-03
536	1	0.47129E-01
536	2	0.44690E-02
536	3	0.78384E-01
536	4	-.27001E-06
536	5	-.48405E-04
536	6	0.26252E-05
537	1	0.57527E-01
537	2	0.41668E-02
537	3	0.73011E-01
537	4	0.50060E-07
537	5	-.32448E-04
537	6	0.24435E-05
538	1	0.66883E-01
538	2	0.37531E-02
538	3	0.65748E-01
538	4	0.13703E-06
538	5	-.19343E-04
538	6	0.34236E-06
539	1	0.79894E-01
539	2	0.34411E-02
539	3	0.60259E-01
539	4	0.14057E-06
539	5	-.51000E-03
539	6	0.29753E-04
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540	2	0.19366E-02
540	3	0.33827E-01
540	4	-.49389E-06
540	5	0.36686E-02
540	6	-.20930E-03
541	1	0.20738E-01
541	2	0.11504E-02
541	3	0.40059E-01
541	4	0.27581E-06
541	5	-.28254E-02
541	6	0.81133E-04
542	1	0.47125E-01
542	2	0.22435E-02
542	3	0.78473E-01

542	4	0.64177E-06
542	5	-.47658E-04
542	6	0.28976E-06
543	1	0.57537E-01
543	2	0.20835E-02
543	3	0.73110E-01
543	4	-.48290E-06
543	5	-.34066E-04
543	6	0.17033E-05
544	1	0.66879E-01
544	2	0.18727E-02
544	3	0.65827E-01
544	4	-.94925E-06
544	5	-.16490E-04
544	6	0.75914E-06
545	1	0.79880E-01
545	2	0.17205E-02
545	3	0.60325E-01
545	4	0.11105E-05
545	5	-.51247E-03
545	6	0.14472E-04
546	1	0.50900E-01
546	2	0.97261E-03
546	3	0.33869E-01
546	4	0.34371E-06
546	5	0.36730E-02
546	6	-.10575E-03
547	1	0.10369E-01
547	2	0.28975E-03
547	3	0.20035E-01
547	4	0.76639E-03
547	5	-.14132E-02
547	6	-.37621E-03
548	1	0.23562E-01
548	2	0.56525E-03
548	3	0.39250E-01
548	4	0.14607E-02
548	5	-.23931E-04
548	6	-.87750E-03
549	1	0.28770E-01
549	2	0.52308E-03
549	3	0.36571E-01
549	4	0.13249E-02
549	5	-.17172E-04
549	6	-.10431E-02
550	1	0.33443E-01

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 550   2  0.47001E-03
 550   3  0.32931E-01
 550   4  0.11530E-02
 550   5  -.79777E-05
 550   6  -.11721E-02
 551   1  0.39942E-01
 551   2  0.43194E-03
 551   3  0.30175E-01
 551   4  0.10200E-02
 551   5  -.25748E-03
 551   6  -.13485E-02
 552   1  0.25443E-01
 552   2  0.24306E-03
 552   3  0.16934E-01
 552   4  0.53623E-03
 552   5  0.18383E-02
 552   6  -.83207E-03
*FREQ 0 4
 10  0.31415927E+02 3500.00
 50  3500.0        20000.0
 300  20000.00      32000.00
 10  32000.00      0.62831855E+05
*MONITOR
STRESS LAYER 1  NODE 186 COMPONENT 2
*PRINT
TOTALDISPLACEMENT
STRESS
*END
```

Appendix B
NESSUS/PFEM Annotated Input Deck for the Base Line Case

```
 *PFEM
*ZFDEFINE
 *COMPUTATIONALMETHOD 1 11
  1
  2
  3
  4
  5
  6
  7
  8
  9
  10
  11
C Explicit variables are PHI (Fatigue Property) and KT (Stress Concentration)
 *EXPLICITVARIABLES 2
  12
  13
C Coefficients are passed to UZFUNCTION
C The first value is the start index of the CLS data passed to CLS Routines
C The second is the start index of correlation model passed to UPSHRO routine
C The third value is the start index for the fatigue data passed to Fatige module
C Total 69 coefficients
 *ZFUNCTION 1 69
  4
  20
  30
   1.09
   7
   33
   31
   19
   24
   12
   17
   21
   6
   59
   28
   47
   68
   67
```

71
1.0
1500.0
0.85
2.0
1500.0
0.142
-0.9501
0.0000
0.5761
0.00
1
4.5
15
48888
10
44777
100
43000
300
41888
600
41000
1000
39333
3000
38333
6000
37444
11400
37111
30000
36888
60000
36666
100000
36333
300000
36000
1000000
35666
3000000
35222
10000000
31000
53000

```
    1000.0
    1.0
    2.0
    1.80
    0.00
C
  *CVARIABLE 1
C   R.S.S. OF THE TWO SPECTRAL CASES
    RESPTYPE 93
    LAYER 1
    NODELIST  1
    186
    CONDITIONLIST 2
    1
    2
    COMPONENTLIST 1
    2
    OPERATION  1 0
    UOPERATION
    END
  *CVARIABLE 2
C   STRESS VELOCITY FROM THE TWO SPECTRAL CASES
    RESPTYPE 96
    LAYER 1
    NODELIST  1
    186
    CONDITIONLIST 2
    1
    2
    COMPONENTLIST 1
    2
    OPERATION  1 0
    UOPERATION
    END
  *UZFUNCTION
 *END
C The first seven variables are engine system CLS random variables
C The eighth variable is the convection to free stream velocity multiplier
 *RVDEFINE
  *DEFINE 1
  MCC-HGIR
  1.88E-03  4.7E-05     NORMAL
  COEFF
  1 1.0
  2 0.0
  3 0.0
```

4 0.0
5 0.0
6 0.0
7 0.0
8 0.0
9 0.0
10 0.0
*DEFINE 2
HGM-O-R
4.213E-3 2.1065E-4 NORMAL
COEFF
1 0.0
3 0.0
4 0.0
5 0.0
6 0.0
7 0.0
8 0.0
9 0.0
10 0.0
*DEFINE 3
HPFT-EM
.994762 9.94762E-3 NORMAL
COEFF
1 0.0
2 0.0
3 1.0
4 0.0
5 0.0
6 0.0
7 0.0
8 0.0
9 0.0
10 0.0
*DEFINE 4
HPOT-EM
0.960487 9.60487E-3 NORMAL
COEFF
1 0.0
2 0.0
3 0.0
4 1.0
5 0.0
6 0.0
7 0.0
8 0.0

9 0.0
10 0.0
*DEFINE 5
MCC-TH-D
1.02897E+01 1.02897E-02 NORMAL
COEFF
1 0.0
2 0.0
3 0.0
4 0.0
5 1.0
6 0.0
7 0.0
8 0.0
9 0.0
10 0.0
*DEFINE 6
HPFP-EM
1.0142 8.1136E-3 NORMAL
COEFF
1 0.0
2 0.0
3 0.0
4 0.0
5 0.0
6 1.0
7 0.0
8 0.0
9 0.0
10 0.0
*DEFINE 7
HPOP-EM
0.94458 3.778E-3 NORMAL
COEFF
1 0.0
2 0.0
3 0.0
4 0.0
5 0.0
6 0.0
7 1.0
8 0.0
9 0.0
10 0.0
*DEFINE 8
CONV

```
   0.72 0.050  NORMAL
   COEFF
   1 0.0
   2 0.0
   3 0.0
   4 0.0
   5 0.0
   6 0.0
   7 0.0
   8 1.0
   9 0.0
   10 0.0
C The ninth random variable is the thickness of the inner vane
   *DEFINE 9
   TH_IN
   0.052 .002 NORMAL
   COOR
1   0.000000  0.000000  0.000000  1.000000
2   0.000000  0.000000  0.000000  1.000000
3   0.000000  0.000000  0.000000  1.000000
4   0.000000  0.000000  0.000000  1.000000
5   0.000000  0.000000  0.000000  1.000000
6   0.000000  0.000000  0.000000  1.000000
7   0.000000  0.000000  0.000000  1.000000
8   0.000000  0.000000  0.000000  1.000000
9   0.000000  0.000000  0.000000  1.000000
10  0.000000  0.000000  0.000000  1.000000
11  0.000000  0.000000  0.000000  1.000000
12  0.000000  0.000000  0.000000  1.000000
13  0.000000  0.000000  0.000000  1.000000
14  0.000000  0.000000  0.000000  1.000000
15  0.000000  0.000000  0.000000  1.000000
16  0.000000  0.000000  0.000000  1.000000
17  0.000000  0.000000  0.000000  1.000000
18  0.000000  0.000000  0.000000  1.000000
19  0.000000  0.000000  0.000000  1.000000
20  0.000000  0.000000  0.000000  1.000000
21  0.000000  0.000000  0.000000  1.000000
22  0.000000  0.000000  0.000000  1.000000
23  0.000000  0.000000  0.000000  1.000000
24  0.000000  0.000000  0.000000  1.000000
25  0.000000  0.000000  0.000000  1.000000
26  0.000000  0.000000  0.000000  1.000000
27  0.000000  0.000000  0.000000  1.000000
28  0.000000  0.000000  0.000000  1.000000
29  0.000000  0.000000  0.000000  1.000000
```

30	0.000000	0.000000	0.000000	1.000000
31	0.000000	0.000000	0.000000	1.000000
32	0.000000	0.000000	0.000000	1.000000
33	0.000000	0.000000	0.000000	1.000000
34	0.000000	0.000000	0.000000	1.000000
35	0.000000	0.000000	0.000000	1.000000
36	0.000000	0.000000	0.000000	1.000000
37	0.000000	0.000000	0.000000	1.000000
38	0.000000	0.000000	0.000000	1.000000
39	0.000000	0.000000	0.000000	1.000000
40	0.000000	0.000000	0.000000	1.000000
41	0.000000	0.000000	0.000000	1.000000
42	0.000000	0.000000	0.000000	1.000000
43	0.000000	0.000000	0.000000	1.000000
44	0.000000	0.000000	0.000000	1.000000
45	0.000000	0.000000	0.000000	1.000000
46	0.000000	0.000000	0.000000	1.000000
47	0.000000	0.000000	0.000000	1.000000
48	0.000000	0.000000	0.000000	1.000000
49	0.000000	0.000000	0.000000	1.000000
50	0.000000	0.000000	0.000000	1.000000
51	0.000000	0.000000	0.000000	1.000000
52	0.000000	0.000000	0.000000	1.000000
53	0.000000	0.000000	0.000000	1.000000
54	0.000000	0.000000	0.000000	1.000000
55	0.000000	0.000000	0.000000	1.000000
56	0.000000	0.000000	0.000000	1.000000
57	0.000000	0.000000	0.000000	1.000000
58	0.000000	0.000000	0.000000	1.000000
59	0.000000	0.000000	0.000000	1.000000
60	0.000000	0.000000	0.000000	1.000000
61	0.000000	0.000000	0.000000	1.000000
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63	0.000000	0.000000	0.000000	1.000000
64	0.000000	0.000000	0.000000	1.000000
65	0.000000	0.000000	0.000000	1.000000
66	0.000000	0.000000	0.000000	1.000000
67	0.000000	0.000000	0.000000	1.000000
68	0.000000	0.000000	0.000000	1.000000
69	0.000000	0.000000	0.000000	1.000000
70	0.000000	0.000000	0.000000	1.000000
71	0.000000	0.000000	0.000000	1.000000
72	0.000000	0.000000	0.000000	1.000000
73	0.000000	0.000000	0.000000	1.000000
74	0.000000	0.000000	0.000000	1.000000
75	0.000000	0.000000	0.000000	1.000000

76	0.000000	0.000000	0.000000	1.000000
77	0.000000	0.000000	0.000000	1.000000
78	0.000000	0.000000	0.000000	1.000000
79	0.000000	0.000000	0.000000	1.000000
80	0.000000	0.000000	0.000000	1.000000
81	0.000000	0.000000	0.000000	1.000000
82	0.000000	0.000000	0.000000	1.000000
83	0.000000	0.000000	0.000000	1.000000
84	0.000000	0.000000	0.000000	1.000000
85	0.000000	0.000000	0.000000	1.000000
86	0.000000	0.000000	0.000000	1.000000
87	0.000000	0.000000	0.000000	1.000000
88	0.000000	0.000000	0.000000	1.000000
89	0.000000	0.000000	0.000000	1.000000
90	0.000000	0.000000	0.000000	1.000000
91	0.000000	0.000000	0.000000	1.000000
92	0.000000	0.000000	0.000000	1.000000
93	0.000000	0.000000	0.000000	1.000000
94	0.000000	0.000000	0.000000	1.000000
95	0.000000	0.000000	0.000000	1.000000
96	0.000000	0.000000	0.000000	1.000000
97	0.000000	0.000000	0.000000	1.000000
98	0.000000	0.000000	0.000000	1.000000
99	0.000000	0.000000	0.000000	1.000000
100	0.000000	0.000000	0.000000	1.000000
101	0.000000	0.000000	0.000000	1.000000
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103	0.000000	0.000000	0.000000	1.000000
104	0.000000	0.000000	0.000000	1.000000
105	0.000000	0.000000	0.000000	1.000000
106	0.000000	0.000000	0.000000	1.000000
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108	0.000000	0.000000	0.000000	1.000000
109	0.000000	0.000000	0.000000	1.000000
110	0.000000	0.000000	0.000000	1.000000
111	0.000000	0.000000	0.000000	1.000000
112	0.000000	0.000000	0.000000	1.000000
113	0.000000	0.000000	0.000000	1.000000
114	0.000000	0.000000	0.000000	1.000000
115	0.000000	0.000000	0.000000	1.000000
116	0.000000	0.000000	0.000000	1.000000
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119	0.000000	0.000000	0.000000	1.000000
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121	0.000000	0.000000	0.000000	1.000000

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123	0.000000	0.000000	0.000000	1.000000
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133	0.000000	0.000000	0.000000	1.000000
134	0.000000	0.000000	0.000000	1.000000
135	0.000000	0.000000	0.000000	1.000000
136	0.000000	0.000000	0.000000	1.000000
137	0.000000	0.000000	0.000000	1.000000
138	0.000000	0.000000	0.000000	1.000000
139	0.000000	0.000000	0.000000	1.000000
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145	0.000000	0.000000	0.000000	1.000000
146	0.000000	0.000000	0.000000	1.000000
147	0.000000	0.000000	0.000000	1.000000
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149	0.000000	0.000000	0.000000	1.000000
150	0.000000	0.000000	0.000000	1.000000
151	0.000000	0.000000	0.000000	1.000000
152	0.000000	0.000000	0.000000	1.000000
153	0.000000	0.000000	0.000000	1.000000
154	0.000000	0.000000	0.000000	1.000000
155	0.000000	0.000000	0.000000	1.000000
156	0.000000	0.000000	0.000000	1.000000
157	0.000000	0.000000	0.000000	1.000000
158	0.000000	0.000000	0.000000	1.000000
159	0.000000	0.000000	0.000000	1.000000
160	0.000000	0.000000	0.000000	1.000000
161	0.000000	0.000000	0.000000	1.000000
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164	0.000000	0.000000	0.000000	1.000000
165	0.000000	0.000000	0.000000	1.000000
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174	0.000000	0.000000	0.000000	1.000000
175	0.000000	0.000000	0.000000	1.000000
176	0.000000	0.000000	0.000000	1.000000
177	0.000000	0.000000	0.000000	1.000000
178	0.000000	0.000000	0.000000	1.000000
179	0.000000	0.000000	0.000000	1.000000
180	0.000000	0.000000	0.000000	1.000000
181	0.000000	0.000000	0.000000	1.000000
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183	0.000000	0.000000	0.000000	1.000000
184	0.000000	0.000000	0.000000	1.000000
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189	0.000000	0.000000	0.000000	1.000000
190	0.000000	0.000000	0.000000	1.000000
191	0.000000	0.000000	0.000000	1.000000
192	0.000000	0.000000	0.000000	1.000000
193	0.000000	0.000000	0.000000	1.000000
194	0.000000	0.000000	0.000000	1.000000
195	0.000000	0.000000	0.000000	1.000000
196	0.000000	0.000000	0.000000	1.000000
197	0.000000	0.000000	0.000000	1.000000
198	0.000000	0.000000	0.000000	1.000000
199	0.000000	0.000000	0.000000	1.000000
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201	0.000000	0.000000	0.000000	1.000000
202	0.000000	0.000000	0.000000	1.000000
203	0.000000	0.000000	0.000000	1.000000
204	0.000000	0.000000	0.000000	1.000000
205	0.000000	0.000000	0.000000	1.000000
206	0.000000	0.000000	0.000000	1.000000
207	0.000000	0.000000	0.000000	1.000000
208	0.000000	0.000000	0.000000	1.000000
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210	0.000000	0.000000	0.000000	1.000000
211	0.000000	0.000000	0.000000	1.000000
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213	0.000000	0.000000	0.000000	1.000000

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220	0.000000	0.000000	0.000000	1.000000
221	0.000000	0.000000	0.000000	1.000000
222	0.000000	0.000000	0.000000	1.000000
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224	0.000000	0.000000	0.000000	1.000000
225	0.000000	0.000000	0.000000	1.000000
226	0.000000	0.000000	0.000000	1.000000
227	0.000000	0.000000	0.000000	1.000000
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229	0.000000	0.000000	0.000000	1.000000
230	0.000000	0.000000	0.000000	1.000000
231	0.000000	0.000000	0.000000	1.000000
232	0.000000	0.000000	0.000000	1.000000
233	0.000000	0.000000	0.000000	1.000000
234	0.000000	0.000000	0.000000	1.000000
235	0.000000	0.000000	0.000000	1.000000
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245	0.000000	0.000000	0.000000	1.000000
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251	0.000000	0.000000	0.000000	1.000000
252	0.000000	0.000000	0.000000	1.000000
253	0.000000	0.000000	0.000000	1.000000
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255	0.000000	0.000000	0.000000	1.000000
256	0.000000	0.000000	0.000000	1.000000
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260	0.000000	0.000000	0.000000	1.000000
261	0.000000	0.000000	0.000000	1.000000
262	0.000000	0.000000	0.000000	1.000000
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264	0.000000	0.000000	0.000000	1.000000
265	0.000000	0.000000	0.000000	1.000000
266	0.000000	0.000000	0.000000	1.000000
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269	0.000000	0.000000	0.000000	1.000000
270	0.000000	0.000000	0.000000	1.000000
271	0.000000	0.000000	0.000000	1.000000
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275	0.000000	0.000000	0.000000	1.000000
276	0.000000	0.000000	0.000000	1.000000
277	0.000000	0.000000	0.000000	1.000000
278	0.000000	0.000000	0.000000	1.000000
279	0.000000	0.000000	0.000000	1.000000
280	0.000000	0.000000	0.000000	1.000000
281	0.000000	0.000000	0.000000	1.000000
282	0.000000	0.000000	0.000000	1.000000
283	0.000000	0.000000	0.000000	1.000000
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285	0.000000	0.000000	0.000000	1.000000
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288	0.000000	0.000000	0.000000	1.000000
289	0.000000	0.000000	0.000000	1.000000
290	0.000000	0.000000	0.000000	1.000000
291	0.000000	0.000000	0.000000	1.000000
292	0.000000	0.000000	0.000000	1.000000
293	0.000000	0.000000	0.000000	1.000000
294	0.000000	0.000000	0.000000	1.000000
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297	0.000000	0.000000	0.000000	1.000000
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300	0.000000	0.000000	0.000000	1.000000
301	0.000000	0.000000	0.000000	1.000000
302	0.000000	0.000000	0.000000	1.000000
303	0.000000	0.000000	0.000000	1.000000
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305	0.000000	0.000000	0.000000	1.000000

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316	0.000000	0.000000	0.000000	1.000000
317	0.000000	0.000000	0.000000	1.000000
318	0.000000	0.000000	0.000000	1.000000
319	0.000000	0.000000	0.000000	1.000000
320	0.000000	0.000000	0.000000	1.000000
321	0.000000	0.000000	0.000000	1.000000
322	0.000000	0.000000	0.000000	1.000000
323	0.000000	0.000000	0.000000	1.000000
324	0.000000	0.000000	0.000000	1.000000
325	0.000000	0.000000	0.000000	1.000000
326	0.000000	0.000000	0.000000	1.000000
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331	0.000000	0.000000	0.000000	1.000000
332	0.000000	0.000000	0.000000	1.000000
333	0.000000	0.000000	0.000000	1.000000
334	0.000000	0.000000	0.000000	1.000000
335	0.000000	0.000000	0.000000	1.000000
336	0.000000	0.000000	0.000000	1.000000
337	0.000000	0.000000	0.000000	1.000000
338	0.000000	0.000000	0.000000	1.000000
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340	0.000000	0.000000	0.000000	1.000000
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343	0.000000	0.000000	0.000000	1.000000
344	0.000000	0.000000	0.000000	1.000000
345	0.000000	0.000000	0.000000	1.000000
346	0.000000	0.000000	0.000000	1.000000
347	0.000000	0.000000	0.000000	1.000000
348	0.000000	0.000000	0.000000	1.000000
349	0.000000	0.000000	0.000000	1.000000
350	0.000000	0.000000	0.000000	1.000000
351	0.000000	0.000000	0.000000	1.000000

```
352   0.000000   0.000000   0.000000   1.000000
353   0.000000   0.000000   0.000000   1.000000
354   0.000000   0.000000   0.000000   1.000000
355   0.000000   0.000000   0.000000   1.000000
356   0.000000   0.000000   0.000000   1.000000
357   0.000000   0.000000   0.000000   1.000000
358   0.000000   0.000000   0.000000   1.000000
359   0.000000   0.000000   0.000000   1.000000
360   0.000000   0.000000   0.000000   1.000000
361   0.000000   0.000000   0.000000   1.000000
362   0.000000   0.000000   0.000000   1.000000
363   0.000000   0.000000   0.000000   1.000000
364   0.000000   0.000000   0.000000   1.000000
365   0.000000   0.000000   0.000000   1.000000
366   0.000000   0.000000   0.000000   1.000000
C The tenth random variable is the thickness of the outer vane
*DEFINE 10
 TH_OU
 0.06 .0024 NORMAL
 COOR
367   0.000000   0.000000   0.000000   1.000000
368   0.000000   0.000000   0.000000   1.000000
369   0.000000   0.000000   0.000000   1.000000
370   0.000000   0.000000   0.000000   1.000000
371   0.000000   0.000000   0.000000   1.000000
372   0.000000   0.000000   0.000000   1.000000
373   0.000000   0.000000   0.000000   1.000000
374   0.000000   0.000000   0.000000   1.000000
375   0.000000   0.000000   0.000000   1.000000
376   0.000000   0.000000   0.000000   1.000000
377   0.000000   0.000000   0.000000   1.000000
378   0.000000   0.000000   0.000000   1.000000
379   0.000000   0.000000   0.000000   1.000000
380   0.000000   0.000000   0.000000   1.000000
381   0.000000   0.000000   0.000000   1.000000
382   0.000000   0.000000   0.000000   1.000000
383   0.000000   0.000000   0.000000   1.000000
384   0.000000   0.000000   0.000000   1.000000
385   0.000000   0.000000   0.000000   1.000000
386   0.000000   0.000000   0.000000   1.000000
387   0.000000   0.000000   0.000000   1.000000
388   0.000000   0.000000   0.000000   1.000000
389   0.000000   0.000000   0.000000   1.000000
390   0.000000   0.000000   0.000000   1.000000
391   0.000000   0.000000   0.000000   1.000000
392   0.000000   0.000000   0.000000   1.000000
```

393	0.000000	0.000000	0.000000	1.000000
394	0.000000	0.000000	0.000000	1.000000
395	0.000000	0.000000	0.000000	1.000000
396	0.000000	0.000000	0.000000	1.000000
397	0.000000	0.000000	0.000000	1.000000
398	0.000000	0.000000	0.000000	1.000000
399	0.000000	0.000000	0.000000	1.000000
400	0.000000	0.000000	0.000000	1.000000
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402	0.000000	0.000000	0.000000	1.000000
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404	0.000000	0.000000	0.000000	1.000000
405	0.000000	0.000000	0.000000	1.000000
406	0.000000	0.000000	0.000000	1.000000
407	0.000000	0.000000	0.000000	1.000000
408	0.000000	0.000000	0.000000	1.000000
409	0.000000	0.000000	0.000000	1.000000
410	0.000000	0.000000	0.000000	1.000000
411	0.000000	0.000000	0.000000	1.000000
412	0.000000	0.000000	0.000000	1.000000
413	0.000000	0.000000	0.000000	1.000000
414	0.000000	0.000000	0.000000	1.000000
415	0.000000	0.000000	0.000000	1.000000
416	0.000000	0.000000	0.000000	1.000000
417	0.000000	0.000000	0.000000	1.000000
418	0.000000	0.000000	0.000000	1.000000
419	0.000000	0.000000	0.000000	1.000000
420	0.000000	0.000000	0.000000	1.000000
421	0.000000	0.000000	0.000000	1.000000
422	0.000000	0.000000	0.000000	1.000000
423	0.000000	0.000000	0.000000	1.000000
424	0.000000	0.000000	0.000000	1.000000
425	0.000000	0.000000	0.000000	1.000000
426	0.000000	0.000000	0.000000	1.000000
427	0.000000	0.000000	0.000000	1.000000
428	0.000000	0.000000	0.000000	1.000000
429	0.000000	0.000000	0.000000	1.000000
430	0.000000	0.000000	0.000000	1.000000
431	0.000000	0.000000	0.000000	1.000000
432	0.000000	0.000000	0.000000	1.000000
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434	0.000000	0.000000	0.000000	1.000000
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436	0.000000	0.000000	0.000000	1.000000
437	0.000000	0.000000	0.000000	1.000000
438	0.000000	0.000000	0.000000	1.000000

439	0.000000	0.000000	0.000000	1.000000
440	0.000000	0.000000	0.000000	1.000000
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442	0.000000	0.000000	0.000000	1.000000
443	0.000000	0.000000	0.000000	1.000000
444	0.000000	0.000000	0.000000	1.000000
445	0.000000	0.000000	0.000000	1.000000
446	0.000000	0.000000	0.000000	1.000000
447	0.000000	0.000000	0.000000	1.000000
448	0.000000	0.000000	0.000000	1.000000
449	0.000000	0.000000	0.000000	1.000000
450	0.000000	0.000000	0.000000	1.000000
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455	0.000000	0.000000	0.000000	1.000000
456	0.000000	0.000000	0.000000	1.000000
457	0.000000	0.000000	0.000000	1.000000
458	0.000000	0.000000	0.000000	1.000000
459	0.000000	0.000000	0.000000	1.000000
460	0.000000	0.000000	0.000000	1.000000
461	0.000000	0.000000	0.000000	1.000000
462	0.000000	0.000000	0.000000	1.000000
463	0.000000	0.000000	0.000000	1.000000
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465	0.000000	0.000000	0.000000	1.000000
466	0.000000	0.000000	0.000000	1.000000
467	0.000000	0.000000	0.000000	1.000000
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469	0.000000	0.000000	0.000000	1.000000
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472	0.000000	0.000000	0.000000	1.000000
473	0.000000	0.000000	0.000000	1.000000
474	0.000000	0.000000	0.000000	1.000000
475	0.000000	0.000000	0.000000	1.000000
476	0.000000	0.000000	0.000000	1.000000
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478	0.000000	0.000000	0.000000	1.000000
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484	0.000000	0.000000	0.000000	1.000000

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504	0.000000	0.000000	0.000000	1.000000
505	0.000000	0.000000	0.000000	1.000000
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507	0.000000	0.000000	0.000000	1.000000
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546	0.000000	0.000000	0.000000	1.000000
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557	0.000000	0.000000	0.000000	1.000000
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562	0.000000	0.000000	0.000000	1.000000
563	0.000000	0.000000	0.000000	1.000000
564	0.000000	0.000000	0.000000	1.000000
565	0.000000	0.000000	0.000000	1.000000
566	0.000000	0.000000	0.000000	1.000000
567	0.000000	0.000000	0.000000	1.000000
568	0.000000	0.000000	0.000000	1.000000
569	0.000000	0.000000	0.000000	1.000000
570	0.000000	0.000000	0.000000	1.000000
571	0.000000	0.000000	0.000000	1.000000
572	0.000000	0.000000	0.000000	1.000000
573	0.000000	0.000000	0.000000	1.000000
574	0.000000	0.000000	0.000000	1.000000
575	0.000000	0.000000	0.000000	1.000000
576	0.000000	0.000000	0.000000	1.000000

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578	0.000000	0.000000	0.000000	1.000000
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580	0.000000	0.000000	0.000000	1.000000
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582	0.000000	0.000000	0.000000	1.000000
583	0.000000	0.000000	0.000000	1.000000
584	0.000000	0.000000	0.000000	1.000000
585	0.000000	0.000000	0.000000	1.000000
586	0.000000	0.000000	0.000000	1.000000
587	0.000000	0.000000	0.000000	1.000000
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597	0.000000	0.000000	0.000000	1.000000
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599	0.000000	0.000000	0.000000	1.000000
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609	0.000000	0.000000	0.000000	1.000000
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611	0.000000	0.000000	0.000000	1.000000
612	0.000000	0.000000	0.000000	1.000000
613	0.000000	0.000000	0.000000	1.000000
614	0.000000	0.000000	0.000000	1.000000
615	0.000000	0.000000	0.000000	1.000000
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617	0.000000	0.000000	0.000000	1.000000
618	0.000000	0.000000	0.000000	1.000000
619	0.000000	0.000000	0.000000	1.000000
620	0.000000	0.000000	0.000000	1.000000
621	0.000000	0.000000	0.000000	1.000000
622	0.000000	0.000000	0.000000	1.000000

623	0.000000	0.000000	0.000000	1.000000
624	0.000000	0.000000	0.000000	1.000000
625	0.000000	0.000000	0.000000	1.000000
626	0.000000	0.000000	0.000000	1.000000
627	0.000000	0.000000	0.000000	1.000000
628	0.000000	0.000000	0.000000	1.000000
629	0.000000	0.000000	0.000000	1.000000
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631	0.000000	0.000000	0.000000	1.000000
632	0.000000	0.000000	0.000000	1.000000
633	0.000000	0.000000	0.000000	1.000000
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639	0.000000	0.000000	0.000000	1.000000
640	0.000000	0.000000	0.000000	1.000000
641	0.000000	0.000000	0.000000	1.000000
642	0.000000	0.000000	0.000000	1.000000
643	0.000000	0.000000	0.000000	1.000000
644	0.000000	0.000000	0.000000	1.000000
645	0.000000	0.000000	0.000000	1.000000
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647	0.000000	0.000000	0.000000	1.000000
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657	0.000000	0.000000	0.000000	1.000000
658	0.000000	0.000000	0.000000	1.000000
659	0.000000	0.000000	0.000000	1.000000
660	0.000000	0.000000	0.000000	1.000000
661	0.000000	0.000000	0.000000	1.000000
662	0.000000	0.000000	0.000000	1.000000
663	0.000000	0.000000	0.000000	1.000000
664	0.000000	0.000000	0.000000	1.000000
665	0.000000	0.000000	0.000000	1.000000
666	0.000000	0.000000	0.000000	1.000000
667	0.000000	0.000000	0.000000	1.000000
668	0.000000	0.000000	0.000000	1.000000

669	0.000000	0.000000	0.000000	1.000000
670	0.000000	0.000000	0.000000	1.000000
671	0.000000	0.000000	0.000000	1.000000
672	0.000000	0.000000	0.000000	1.000000
673	0.000000	0.000000	0.000000	1.000000
674	0.000000	0.000000	0.000000	1.000000
675	0.000000	0.000000	0.000000	1.000000
676	0.000000	0.000000	0.000000	1.000000
677	0.000000	0.000000	0.000000	1.000000
678	0.000000	0.000000	0.000000	1.000000
679	0.000000	0.000000	0.000000	1.000000
680	0.000000	0.000000	0.000000	1.000000
681	0.000000	0.000000	0.000000	1.000000
682	0.000000	0.000000	0.000000	1.000000
683	0.000000	0.000000	0.000000	1.000000
684	0.000000	0.000000	0.000000	1.000000
685	0.000000	0.000000	0.000000	1.000000
686	0.000000	0.000000	0.000000	1.000000
687	0.000000	0.000000	0.000000	1.000000
688	0.000000	0.000000	0.000000	1.000000
689	0.000000	0.000000	0.000000	1.000000
690	0.000000	0.000000	0.000000	1.000000
691	0.000000	0.000000	0.000000	1.000000
692	0.000000	0.000000	0.000000	1.000000
693	0.000000	0.000000	0.000000	1.000000
694	0.000000	0.000000	0.000000	1.000000
695	0.000000	0.000000	0.000000	1.000000
696	0.000000	0.000000	0.000000	1.000000
697	0.000000	0.000000	0.000000	1.000000
698	0.000000	0.000000	0.000000	1.000000
699	0.000000	0.000000	0.000000	1.000000
700	0.000000	0.000000	0.000000	1.000000
701	0.000000	0.000000	0.000000	1.000000
702	0.000000	0.000000	0.000000	1.000000
703	0.000000	0.000000	0.000000	1.000000
704	0.000000	0.000000	0.000000	1.000000
705	0.000000	0.000000	0.000000	1.000000
706	0.000000	0.000000	0.000000	1.000000
707	0.000000	0.000000	0.000000	1.000000
708	0.000000	0.000000	0.000000	1.000000
709	0.000000	0.000000	0.000000	1.000000
710	0.000000	0.000000	0.000000	1.000000
711	0.000000	0.000000	0.000000	1.000000
712	0.000000	0.000000	0.000000	1.000000
713	0.000000	0.000000	0.000000	1.000000
714	0.000000	0.000000	0.000000	1.000000

```
715   0.000000   0.000000   0.000000    1.000000
716   0.000000   0.000000   0.000000    1.000000
717   0.000000   0.000000   0.000000    1.000000
718   0.000000   0.000000   0.000000    1.000000
719   0.000000   0.000000   0.000000    1.000000
720   0.000000   0.000000   0.000000    1.000000
721   0.000000   0.000000   0.000000    1.000000
722   0.000000   0.000000   0.000000    1.000000
723   0.000000   0.000000   0.000000    1.000000
724   0.000000   0.000000   0.000000    1.000000
725   0.000000   0.000000   0.000000    1.000000
726   0.000000   0.000000   0.000000    1.000000
727   0.000000   0.000000   0.000000    1.000000
728   0.000000   0.000000   0.000000    1.000000
729   0.000000   0.000000   0.000000    1.000000
730   0.000000   0.000000   0.000000    1.000000
731   0.000000   0.000000   0.000000    1.000000
732   0.000000   0.000000   0.000000    1.000000
C Eleventh random variable is modal damping coefficient
C 20% coefficient of variation - large uncertainty
  *DEFINE 11
   DMP_SCALE
   0.005 0.001  LOGNORMAL
   DAMP 2
    1  50  1.0
   *DEFINE 12
   PHI
   1.0  0.07            LOGNORMAL
C Thirteenth is stress concentration uncertainty
C Rather low is maximum stress occurs on the top side of the vane away
C from the radius
  *DEFINE 13
   Kt
   1.30 0.065  NORMAL
   *PERT 1
   1  1.0
   *PERT 2
   2  1.0
   *PERT 3
   3  1.0
   *PERT 4
   4  1.0
   *PERT 5
   5  1.0
   *PERT 6
   6  1.0
```

```
  *PERT 7
  7 1.0
  *PERT 8
  8 0.5
  *PERT 9
  9 0.5
  *PERT 10
  10 0.5
  *PERT 11
  10 0.001
  11 0.5
  *PERT 12
  12 0.1
  *PERT 13
  13 0.1
 *END
 *MVDEFINE
  *DATATYPE 2
  *RANVARIABLE 13
  1 2 3 4 5 6 7 8 9 10 11 12 13
  *PERTURB 13
  1 2 3 4 5 6 7 8 9 10 11 12 13
 *END
 *AMVDEFINE
  *NODE 1
  *COMPONENT 1
  *CONDITION 1
  *ITERATION
C maximum five iterations for AMV+
   5 0.05
 *END
*END
C
C Start FEM DECK Here
C See Appendix A
C Start of FPI deck
C Linear G function Approximation
C number of data sets is 14
C Probability level approach three levels 0.5, .9, .99
*FPI
 SSME HEX TURN-AROUND VANE PROBLEM
 *RVNUM    13
 *GFUNCTION LINE
 *DATASETNM 14
 *METHOD  FPI
 *ANALTYPE  PLEV
```

```
 *PRINTOPT  LONG
 *END
 *PLEVELS 3
 0.5  0.9  0.99
*END
```

Appendix C
CLS - NESSUS Interface Routines
Called From UPSHRO

```
SUBROUTINE
CLHOTD(PL,IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,P1,LDNAME,IOPT)
C
C     CLHOTD : Component Loads of Oxidizer Turnaround Duct (T/D)
C
C     IDOBJ  : Object (Component Load) ID
C          =  14, Oxidizer Turnaround Duct
C
C     IOPT   : Load function option
C          = 0  Retrieve and Evaluate the load object functions
C          = 1  Retrieve the load names only
C          = 2  Evaluate the object functions only
C
C     TOOTD  : Oxidizer T/D Discharge Temperature, ID=14028
C     POOTD  : Oxidizer T/D Discharge Pressure, ID=14059
C     DPOTD  : Oxidizer T/D Dynamic Pressure (Dynamic Head), ID=14067
C     FLHPOT : HPOT Flow (lbm/sec), ID=14047
C     VELOTD : Oxidizer T/D Velocity (ft/sec), ID=14068
C     AOTD   : Ox T/D Lox Exit Area
C          = 25.229 (in^2) for Block I Engine w ATD pump
C
C
   DIMENSION IBLOAD(*),ICOMB(*),LDNAME(*)
   REAL*8 P1(*)
   REAL*8 TOOTD,POOTD,DPOTD
   REAL*8 FLHPOT,VELOTD,AOTD,DENOTD
   CHARACTER*10 AT,BT,TITLE*20,LDNAME*20
   DATA AOTD/25.229/
C
C***** Oxidizer Turnaround Duct Flow Density, ID=14995
C
   DENOTD(FL,VEL,A) = FL/VEL/A*144
C
C
   IF (IDOBJ.EQ.14) THEN
        AT = 'C14945'
        DO 100 I=1,NRESP
          IF(ICOMB(I).EQ.28) TOOTD  = P1(NOUT+I)
          IF(ICOMB(I).EQ.47) FLHPOT = P1(NOUT+I)
          IF(ICOMB(I).EQ.59) POOTD  = P1(NOUT+I)
          IF(ICOMB(I).EQ.67) DPOTD  = P1(NOUT+I)
```

```
          IF(ICOMB(I).EQ.68) VELOTD = P1(NOUT+I)
 100    CONTINUE
 C      IF (IOPT.EQ.2) GO TO 250
 C        DO 200 J=1,NOUT
 C          IF(IBLOAD(J).EQ.14995) THEN
 C          BT = 'OxTDDen'
 C          TITLE = BT
 C          LDNAME(J) = TITLE
 C          CALL GRSPTT(AT,BT,INT,TITLE,1)
 C          ENDIF
 C  200     CONTINUE
        IF (IOPT.EQ.1) RETURN
 250    CONTINUE
      DO 300 J=1,NOUT
          IF(IBLOAD(J).EQ.14995) P1(J) = DENOTD(FLHPOT,VELOTD,AOTD)
          IF(IBLOAD(J).EQ.14028) P1(J) = TOOTD
          IF(IBLOAD(J).EQ.14047) P1(J) = FLHPOT
          IF(IBLOAD(J).EQ.14059) P1(J) = POOTD
          IF(IBLOAD(J).EQ.14067) P1(J) = DPOTD
          IF(IBLOAD(J).EQ.14068) P1(J) = VELOTD
 300    CONTINUE
    ENDIF
    RETURN
    END
    SUBROUTINE
CLLDDB(LW,NLOAD,NRESP,NOUT,IDPID,ICOMB,ITBCOM,IBLOAD,
   1         CINOM,ANOM,CINF,IGO,P1,P2,NAME,LOADNS,
   2         IPWR,PWR0,PWRATE,NPRPWR,PFPWR,NPRILD,PFILD)
C                                              ANL00020
C     MODULE : CLLDDB                                    ANL00030
C                                              ANL00050
C                                              ANL00060
c   Modified by GEO on Febr 7, 95: - search for available unit for INFILE
c                                  - close unit after reading
c
    logical in_use
    REAL*8 CINOM(64,4),ANOM(25,4),CINF(64,25,4)
    REAL*8 P1(*),P2(*),P3(100)
    REAL*8 PWR0,PWRATE,PFPWR(100,*),PFILD(100,3,*)
    DIMENSION IDPID(*),ICOMB(*),ITBCOM(*),IBLOAD(*)
    DIMENSION IGO(*),LOADNS(*),NPRILD(*)
    CHARACTER*20 NAME(*)
C                                              ANL00210
C                                              ANL00220

    LU = 15
```

```
      inquire(LU,opened=in_use)
      do while (in_use)
       lu=lu+1
       inquire(LU,opened=in_use)
      enddo
      write(*,*) 'from CLLDDB: unit ',lu,' is used for INFILE'
      OPEN(LU,FILE='INFILE',status='old')
      WRITE(LW,'(///1X,''***** Retrieve CLS Load Database *****'')')
      WRITE(LW,'(1X,''***************************************''/)')
C                                                     ANL00330
      READ(LU,103) IPWR,PWR0,PWRATE
      IF (IPWR.EQ.2) THEN
         READ(LU,101) NPRPWR
         READ(LU,104) ((PFPWR(I,J),J=1,3),I=1,NPRPWR)
      ENDIF
      READ(LU,101) NLOAD                                  ANL01030
101   FORMAT(I6)
      WRITE(LW,'(///1X,''No. of Available Indep. loads ='',I6)') NLOAD
      IF (NLOAD.NE.0) THEN                                ANL01050
      DO 200 I=1,NLOAD                                    ANL01060
      READ(LU,102) IDPID(I),NAME(I),LOADNS(I)                     ANL01070
102   FORMAT(I6,A20,4X,I6)                                ANL00760
      WRITE(LW,1200) I,IDPID(I),NAME(I),LOADNS(I)
1200  FORMAT(//,' For variable ',I6/' IDP Load ID  ',I6,' : ',A
     1/1X,' DUTY-CYCLE-DATA INPUT, =1 YES; =0 NO : ',I2/)         ANL01100
      READ(LU,104)(CINOM(I,JJ),JJ=1,4)                    ANL01110
104   FORMAT(6E12.5)                                      ANL00950
      READ(LU,103) IGO(I),P1(I),P2(I),P3(I)               ANL01120
103   FORMAT(I6,3E12.5)                                   ANL00790
      WRITE(LW,707) IGO(I)
      WRITE(LW,708) P1(I),P2(I),P3(I)
      IF (LOADNS(I).EQ.1) THEN                            ANL01210
        READ(LU,101) NPAIR                                ANL01220
        NPRILD(I) = NPAIR                                 ANL01230
        READ(LU,104) ((PFILD(K,J,I),J=1,3),K=1,NPAIR)             ANL01240
        WRITE(LW,1230)
1230      FORMAT(1X,'LOAD PROFILE(Time,Load,Std.Dev)')
        WRITE(LW,1220) ((PFILD(K,J,I),J=1,3),K=1,NPAIR)
1220  FORMAT(5X,6E12.5)
      ENDIF                                               ANL01280
200   CONTINUE                                            ANL01290
      ENDIF                                               ANL01300
C                                                         ANL01480
C                                                         ANL01490
305   CONTINUE                                            ANL01500
      READ(LU,101) NRESP                                  ANL01510
```

```
      WRITE(LW,'(///1X,"No. of System Dependent Loads =",I6)') NRESP
      IF (NRESP.EQ.0) GO TO 410                                    ANL01530
      IB = NLOAD                                                   ANL01540
      DO 400 I=1,NRESP                                             ANL01550
      READ(LU,303) ICOMB(I),NAME(IB+I)                             ANL01560
  303 FORMAT(I6,A20,4X,E12.5)                                      ANL01570
      WRITE(LW,1250) I,ICOMB(I),NAME(IB+I)
 1250 FORMAT(//,1X,' For Dependent Load ',I6/
     &         1X,'      Dep. Load ID ',I6,' : ',A)                ANL01600
      IF (ICOMB(I).GE.0) THEN                                      ANL01610
      READ(LU,104) (ANOM(I,JJ),JJ=1,4)                             ANL01620
      IF (NLOAD.NE.0) THEN                                         ANL01630
      DO 350 J=1,NLOAD                                             ANL01640
      READ(LU,104) (CINF(J,I,JJ),JJ=1,4)                           ANL01650
  350 CONTINUE                                                     ANL01660
      ENDIF
      ENDIF
  400 CONTINUE                                                     ANL02270
  410 CONTINUE                                                     ANL02280
C                                                                  ANL02290
C                                                                  ANL02300
      READ(LU,101) NOUT                                            ANL02320
      WRITE(LW,'(///1X,"No. of Available Component Loads =",I6)')NOUT
      IF (NOUT.NE.0) THEN                                          ANL02330
      IB=NLOAD+NRESP                                               ANL02340
      DO 500 I=1,NOUT                                              ANL02350
      READ(LU,101) ITBCOM(I)                                       ANL02370
      READ(LU,102) IBLOAD(I),NAME(IB+I)                            ANL02380
      READ(LU,103) IGO(IB+I),P1(IB+I),P2(IB+I),P3(IB+I)
      WRITE(LW,1260) I,IBLOAD(I),NAME(IB+I)
 1260 FORMAT(//,1X,' For Component Load ',I6/
     &         1X,'     Comp. Load ID ',I6,' : ',A)
  500 CONTINUE                                                     ANL02660
      ENDIF                                                        ANL02740
      close(lu)
      RETURN                                                       ANL03440
  707 FORMAT(1X,12I6)                                              ANL03450
  708 FORMAT(6(1X,1PE12.5))                                        ANL03460
  711 FORMAT(1X,I6,A20,4X,I6)                                      ANL03490
      END                                                          ANL03520
      SUBROUTINE CLOBJS(PL,IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,P1,P2,
     1            LDNAME,IOPT)
C
C     CLOBJS : Component Load Object Functions
C
C     CLLOXP : Component Loads of LOX Post, IDOBJ = 6
```

```
C     CLHODD : HPOTP Discharge Duct, IDOBJ = 10
C     CLMCCL : MCC liner, IDOBJ = 12
C     CLHOTD : Oxidizer Turnaround Duct (Ox T/D), IDOBJ = 14
C
C     IDOBJ  : Object (Component Load) ID
C
C     IOPT   : Load function option
C          = 0  Evaluate the load object functions & Retrieve
C               load names
C          = 1  Retrieve the load names only
C          = 2  Evaluate load object functions only
C
      DIMENSION IBLOAD(*),ICOMB(*),LDNAME(*)
      REAL*8 P1(*),P2(*)
      CHARACTER LDNAME*20
C       IF (IDOBJ.EQ.6) THEN
C         CALL CLLOXP(PL,IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,P1,LDNAME)
C       ELSE IF (IDOBJ.EQ.10) THEN
C         CALL CLHODD(PL,IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,P1,LDNAME)
      IF (IDOBJ.EQ.12) THEN
c         CALL CLMCCL(PL,IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,P1,P2,
c    1            LDNAME,IOPT)
      ELSE IF (IDOBJ.EQ.14) THEN
          CALL
CLHOTD(PL.IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,P1,LDNAME,IOPT)
      ENDIF
      RETURN
      END
      SUBROUTINE
CLSICM(LW.PL.NIRV,IDIRV,VIRV,NDRV,IDDRV,VDRV,IOPOBJ)
C
C      CLSICM  supplies component loads as requested in IDDRV
C            A component load object functions routine is supplied
C            for the requested component and the INFILE is prepared
C            for the requested component also.
C
C      Notes :
C         1. The IDIRV independent random variable list composes
C            of system independent variables and component local
C            independent vairables. The system indep. varables
C            and the comp. local varables can be in any order.
C         2. NIRV, IDIRV, VIRV, NDRV, IDDRV can be changed between
C            subroutine calls to CLSICM (i.e. this module).
C         3. The nominal values of the component local independent
C            loads are supplied by subroutine CLLDDB which reads
C            in the values from INFILE.
```

```
C
C*********************************************************************
**
C
C       NIRV  : Total number of independent random variables
C               including component local independent variables
C               If the component local independent variable does
C               not change from its mean value, the variable needs
C               not be included in the independent variable list.
C               It is OK though to include it on the list.
C       IDIRV : Independent random variable ID list
C       VIRV  : Input point values of the independent random variables
C       NDRV  : Total number of component random variables including
C               component dependent loads and (if desired) component
C               local independent variables
C       IDDRV : Component random variable ID list
C       VDRV  : OUTPUT values of the component random variables
C
C       IOPOBJ: Options
C            = 1 , Load names retrieval only
C            = 2 , Loads (not normalized) evaluation
C            = 3 , Normalized loads evaluation
C
C       PP1   : Variable (instantaneous) point values
C       PP2   : Delta values (the differences) of PP1 from the means
C
C*********************************************************************
**
      COMMON /BLOCK0/NAME(100)
      COMMON
/BLOCK1/NLOAD,NRESP,NOUT,IDPID(64),ICOMB(25),ITBCOM(20),
     1        IBLOAD(20)
      COMMON /RATED/ ANOM(25,4),CINOM(64,4),CINF(64,25,4)
      COMMON /DISTR/ IGO(100),P1(100),P2(100),P3(100),LOADNS(64)
      DIMENSION IDIRV(*),IDDRV(*),IDVX(100),NPRILD(15)
      REAL*8 PWR0,PWRATE,PFPWR(100,3),PFILD(100,3,15)
      REAL*8 VIRV(*),VDRV(*),VX(100),VXDEL(100),VY(20),VYDEL(20)
      REAL*8 CXNOM(64,4),CYNOM(25,4),CXYINF(64,25,4),PP1(100),PP2(100)
      REAL*8 CINOM,ANOM,CINF,P1,P2,P3
      CHARACTER*20 LDNAME(100),NAME,FMT*60
      DATA ILDDB/0/
C
C     CALL CLLDDB to obtain load database
C
      IF (LW.NE.6) OPEN(LW,STATUS='SCRATCH')
      IF (ILDDB.EQ.0) THEN
```

```
      CALL CLLDDB(LW,NLOAD,NRESP,NOUT,IDPID,ICOMB,ITBCOM,IBLOAD,
     1           CINOM,ANOM,CINF,IGO,P1,P2,NAME,LOADNS,
     2           IPWR,PWR0,PWRATE,NPRPWR,PFPWR,NPRILD,PFILD)
      ILDDB = 1
      ENDIF
C
C     Initialize the component and its local loads
C
      IB = NLOAD+NRESP
      DO 500 I=1,NOUT
      IB = IB+1
      PP1(I) = P1(IB)
      PP2(I) = 0.0
      LDNAME(I) = NAME(IB)
500   CONTINUE
C
C     Matching the requested independent loads
C
      NIDPL = 0
      DO 100 K=1,NRESP
      DO 100 L=1,4
      CYNOM(K,L) = ANOM(K,L)
100   CONTINUE
      DO 220 I=1,NIRV
      DO 200 J=1,NLOAD
C
C     Matching engine system independent variables
C     and retrieving the corresponding influence coefficients
C
      IF (IDPID(J).EQ.IDIRV(I)) THEN
          NIDPL = NIDPL+1
          VX(NIDPL) = VIRV(I)
          IDVX(NIDPL) = IDIRV(I)
          LDNAME(NOUT+NRESP+I) = NAME(J)
          DO 150 L=1,4
          CXNOM(NIDPL,L) = CINOM(J,L)
          DO 120 K=1,NRESP
          CXYINF(NIDPL,K,L) = CINF(J,K,L)
120     CONTINUE
150     CONTINUE
        GO TO 220
      ENDIF
200   CONTINUE
      DO 210 J=1,NOUT
C
C     Matching component local independent variables
```

```
C      and entering them into the load list PP1(.)
C
       IF (IBLOAD(J).EQ.IDIRV(I)) THEN
          PP1(J) = VIRV(I)
          PP1(NOUT+NRESP+I) = PP1(J)
          PP0 = P1(NLOAD+NRESP+J)
          PP2(J) = PP1(J)-PP0
          PP2(NOUT+NRESP+I) = PP2(J)
          LDNAME(NOUT+NRESP+I) = NAME(NLOAD+NRESP+J)
          GO TO 220
       ENDIF
 210  CONTINUE
C
C      Exit the program when one or more requested independent loads
C      are not on the CLS list
C
      WRITE(LW,'(1X,"The independent load is not on the list"/
     1         1X," load ID IDIRV =",I6//)') IDIRV(I)
      STOP
 220  CONTINUE
C
C     System Influence Model
C      IOPINP : Input options
C          = 0   input point values VIRV
C          = 1   input percentage changes in VIRV
C      VXDEL(i) : % change of the i-th independent random variable
C      VYDEL(j) : % change of the j-th dependent random variable
C
C
      IOPINP = 0
      CALL OBSICM(PL,NRESP,NIDPL,CXNOM,CYNOM,CXYINF,
     1          VX,VXDEL,VY,VYDEL,IOPINP)
C
C     Preparing the load list PP1 and PP2
C     for component load evaluation
C
      DO 300 I=1,NRESP
      PP1(NOUT+I) = VY(I)
      PP2(NOUT+I) = VYDEL(I)*VY(I)/(1.0+VYDEL(I))
      LDNAME(NOUT+I) = NAME(NLOAD+I)
 300  CONTINUE
      DO 410 J=1,NIRV
      DO 400 I=1,NIDPL
         IF (IDVX(I).EQ.IDIRV(J)) THEN
        PP1(NOUT+NRESP+J) = VX(I)
        PP2(NOUT+NRESP+J) = VXDEL(I)*VX(I)/(1.0+VXDEL(I))
```

```
      ENDIF
400   CONTINUE
410   CONTINUE
C
C     Component loads evaluation
C
      IDOBJ = ITBCOM(1)
      CALL CLOBJS(PL,IDOBJ,NOUT,NRESP,IBLOAD,ICOMB,PP1,PP2,
     1          LDNAME,IOPOBJ)
C
C     Retrieve component loads and output to screen
C
      FMT = '(1X,2I6,1X,A10,2(1X,1PE12.5))'
      WRITE(LW,'(1X,"Component Loads for Component-ID =",I6)')IDOBJ
      WRITE(LW,'(1X,F6.3)') PL
      DO 1020 I=1,NDRV
      DO 1000 J=1,NOUT
      IF (IBLOAD(J).EQ.IDDRV(I)) THEN
          VDRV(I) = PP1(J)
        WRITE(LW,FMT) ITBCOM(J),IBLOAD(J),LDNAME(J),PP1(J),PP2(J)
          GO TO 1020
      ENDIF
1000  CONTINUE
      DO 1010 K=1,NRESP
      IF (ICOMB(K).EQ.IDDRV(I)) THEN
          VDRV(I) = PP1(K+NOUT)
          GO TO 1020
      ENDIF
1010  CONTINUE
        WRITE(LW,'(1X,"This load is not on the list, IDDRV=",I6)')
     1      IDDRV(I)
1020  CONTINUE
        IZERO = 0
        DO 1100 I=1,NRESP
        WRITE(LW,FMT)
     1    IZERO,ICOMB(I),LDNAME(NOUT+I),PP1(NOUT+I),PP2(NOUT+I)
1100  CONTINUE
        IMONE = -1
        DO 1200 I=1,NIRV
        WRITE(LW,FMT)
     1    IMONE,IDIRV(I),LDNAME(NOUT+NRESP+I),PP1(NOUT+NRESP+I),
     2    PP2(NOUT+NRESP+I)
1200  CONTINUE
      RETURN
      END
      subroutine NESCLSICM(vcoef,pfcoef,upscoef)
```

```
c
c     interface to call the CLS Influence Coefficient Module
c     using variables available in NESSUS
c
c--------|---------|---------|---------|---------|---------|---------|---------|--
c
      implicit none
c
      double precision vcoef,pfcoef,upscoef
      dimension vcoef(10),pfcoef(200),upscoef(11)
c
      integer i,id_flow_m,id_flow_v,id_search,iddrv,idirv,iopobj,
     .      ind_cls,ind_upsrho,lw,ndrv,nirv

      double precision free_fact,vdrv,virv
      real pl
      dimension iddrv(25),idirv(25),vdrv(15),virv(15)
c
      id_flow_v=68
      id_flow_m=47
c
      ind_upsrho=nint(pfcoef(2))
      upscoef(1)=pfcoef(ind_upsrho)
      upscoef(2)=pfcoef(ind_upsrho+1)
      upscoef(3)=pfcoef(ind_upsrho+2)
      upscoef(4)=pfcoef(ind_upsrho+3)
      upscoef(5)=pfcoef(ind_upsrho+4)
      upscoef(6)=pfcoef(ind_upsrho+5)
      upscoef(7)=pfcoef(ind_upsrho+6)
      upscoef(8)=pfcoef(ind_upsrho+7)
      upscoef(9)=pfcoef(ind_upsrho+8)
      lw    =6
      ind_cls=nint(pfcoef(1))
      pl    =pfcoef(ind_cls)
      ind_cls=ind_cls+1
      nirv  =nint(pfcoef(ind_cls))
      do i=1,nirv
       idirv(i)=nint(pfcoef(ind_cls+i))
      enddo
      write(*,*) 'from nesclsicm:'
      write(*,*) 'Power level: ',pl
      write(*,*) 'Independent variables:'
      do i=1,nirv
       virv(i)=vcoef(i)
      write(*,*) idirv(i),virv(i)
      enddo
```

```
      ind_cls=ind_cls+nirv+1
      ndrv   =nint(pfcoef(ind_cls))
      do i=1,ndrv
        iddrv(i)=nint(pfcoef(ind_cls+i))
      enddo
      iopobj=2
      call clsicm(lw,pl,nirv,idirv,virv,ndrv,iddrv,vdrv,iopobj)
      id_search=id_flow_v
      i=1
      do while (iddrv(i).ne.id_search)
        i=i+1
      enddo
C
C     the follwing statement was commneted out by RAJ 04/08/95
C     Change made to bring in the factor as R.V.
C     Debug printout added
C
C     free_fact=pfcoef(ind_upsrho+9)
      free_fact=vcoef(8)
      write(*,*) 'convection velocity factor:', free_fact
C
      upscoef(10)=vdrv(i)*free_fact*12.0d0
      id_search=id_flow_m
      i=1
      do while (iddrv(i).ne.id_search)
        i=i+1
      enddo
      upscoef(11)=vdrv(i)
      write(*,*) 'Flow velocity from NESCLSICM : ',upscoef(10)
      write(*,*) 'Mass flow rate from NESCLSICM: ',upscoef(11)
c
      return
      end
      SUBROUTINE OBSICM(PL,NRESP,NLOAD,XNOM,YNOM,CINF,
RBS00010
     1              XIDPL,XDELT,YDEPL,YDELT,IOPINP)
C                                                   RBS00020
C     OBSICM PERFORMS INFLUENCE COEFFICIENT MODEL
RBS00030
C     DETERMINISTIC POINT CALCULATION                          RBS00040
C                                                   RBS00050
C                                                   RBS00060
C     XIDP0 : Nominal Engine independent load value        RBS00070
C     XIDPL(i): The ith independent load point value       RBS00080
C     XDELT(i): The ith independent load percentage change     RBS00090
C     YDEPL(j): The jth dependent load value           RBS00100
```

```
C     YDELT(j): The jth dependent load percentage change           RBS00110
C
C     XNOM   : X nominal value coefficient set
C     YNOM   : Y nominal value coefficient set
C     CINF   : Influence coefficient set
C
C     IOPINP : Input option, inputs always come from XIDPL
C          = 0  input point values for X in XIDPL
C          = 1  input % changes for X in XIDPL
C
C
      REAL*8 YNOM(25,4),XNOM(64,4),CINF(64,25,4)
      REAL*8 XIDPL(*),XDELT(*),YDEPL(*),YDELT(*)
C     WRITE(LW,'(///)')
C     WRITE(LW,*)' ***** DETERMINISTIC INFLUENCE COEFF. MODEL ***** '
RBS00250
C     WRITE(LW,*)' ************************************************ '
RBS00260
C     WRITE(LW,*)
100   CONTINUE
      DO 200 IL=1,NLOAD                                    RBS00390
C
C      Evaluate the system independent loads
C
      XIDP0 = XNOM(IL,1)                                   RBS00430
        DO 150 J=2,4                                   RBS00440
         XIDP0 = XIDP0+XNOM(IL,J)*PL**(J-1)                     RBS00450
150     CONTINUE                                         RBS00460
      IF (IOPINP.EQ.1) THEN
        XDELT(IL) = XIDPL(IL)                              RBS00480
        XIDPL(IL) = XIDP0*(1.0+XDELT(IL))                        RBS00490
      ELSE                                            RBS00500
        XDELT(IL) = XIDPL(IL)/XIDP0 - 1.0
      ENDIF                                           RBS00520
200   CONTINUE                                           RBS00530
C
C      Engine influence model calculation
C
      DO 400 JL=1,NRESP                                    RBS00540
      YDELT(JL) = 0.0                                    RBS00550
       DO 300 IL=1,NLOAD                                   RBS00560
       CIC = CINF(IL,JL,1)                                RBS00570
         DO 250 J=2,4                                   RBS00580
         CIC = CIC+CINF(IL,JL,J)*PL**(J-1)                     RBS00590
250       CONTINUE                                       RBS00600
       YDELT(JL) = YDELT(JL)+CIC*XDELT(IL)                        RBS00610
```

```
300   CONTINUE                                          RBS00620
    YDEPL(JL) = YNOM(JL,1)                                  RBS00630
      DO 350 J=2,4                                      RBS00640
      YDEPL(JL) = YDEPL(JL)+YNOM(JL,J)*PL**(J-1)                 RBS00650
350   CONTINUE                                          RBS00660
    YDEPL(JL) = YDEPL(JL)*(1.0+YDELT(JL))                       RBS00670
400  CONTINUE                                           RBS00680
    RETURN                                             RBS00970
    END                                              RBS00980
    PROGRAM RBPSAM
C
C     RBPSAM : PSAM module for testing clsicm routines
C
C     IOPOBJ = 1, Retrieve load names only
C            = 2, Evaluate object load functions
C            = 3, Evaluate normalized object load functions
C
C
    DIMENSION IDIRV(25),IDDRV(15)
    REAL*8 VIRV(25),VDRV(15)
C   DATA IDIRV/58,19,17,5,21,59,64,63,12,33,23,3,1,2,4,25,9*0/
C   DATA VIRV/1.0125,1.0355,1.0,164.0,1.02,0.974086,1.0,1.0,10.293,
C  1    0.0031,1.022,100.0,6.0,30.0,37.0,1.0,9*0.0/
C   DATA IDIRV/17,3,20,5,21*0/
C   DATA VIRV/1.0,90.0,1.0,155.0,21*0.0/
C   DATA IDDRV/6048,6029,6072,6020,6550,6017,6091,6535,6530,6531,
C  1      6536,4*0/
C   DATA IDDRV/6550,6535,6048,12*0.0/
C
C     MCC liner test data
C
C     DATA IDIRV/64,63,14,19,1,2,3,4,5,
C    1        12530,12531,12533,12534,12536,12540,10*0/
C     DATA VIRV/1.0,1.0,0.95,1.0355,6.0,30.0,100.0,37.0,164.0,
C    1       1.0,1.0,1.0,1.4,1.0,0.028,10*0.0/
C     DATA IDDRV/12926,12927,12928,12017,12040,12530,12531,12533,
C    1        12534,12536,12540,4*0/
C
C     HPOT Turnaround Duct
C
    DATA IDIRV/33,31,19,24,12,17,21,18*0/
    DATA VIRV /0.00188,0.004213,0.994762,0.960487,10.2897,
   1       1.0142,1.0,18*0.0/
    DATA IDDRV/14995,59,28,47,68,67,9*0/
    LW = 6
    PL = 1.04
```

```
NIRV = 7
NDRV = 6
IOPOBJ = 2
CALL CLSICM(LW,PL,NIRV,IDIRV,VIRV,NDRV,IDDRV,VDRV,IOPOBJ)
WRITE(*,'(///1X," RBPSAM TEST RESULT: ")')
WRITE(*,'(1X," IDDRV    VDRV    ")')
WRITE(*,'(1X,I6,1PE12.5)') (IDDRV(I),VDRV(I),I=1,NDRV)
STOP
END
```

Appendix D
NESSUS Changed Routines

```
C ... SUBROUTINE DATIN1 ... READS THE PARAMETER DATA BLOCK
C
   SUBROUTINE DATIN1
  1  (RWORK ,IWORK ,ISIZE ,VERSNO,MONTH ,JDATE ,NELEM ,NNODE ,
  2   NBC   ,NTIE  ,NMAX  ,NTRAN ,NTRAC ,NPOST ,NLVSUB,NFRSUB,
  3   NEXT  ,JDYN  ,JTEMP ,NPRINT,JREST ,JINC  ,NINC  ,JLOUB ,
  4   JINTER,JEXTRA,JWEIGH,NSTRBC,NTYPE ,MAXSUB,ILAST ,JSUB  ,
  5   NSUB  ,ISTAT ,IDYNM ,ITEST ,JOPTIM,JCREEP,JDIST ,NONISO,
  6   NDYNMD,IDYNMD,NPOSMD,ITHERM,JCONST,NDUP  ,JREPOT,JTANGE,
  7   JTHERM,DALPHA,DBETA ,DGAMMA,JEIGEN,JFORCE,JUTEMP,JUCOEF,
  8   JDISTS,JUHOOK,JDERIV,JUBOUN,JPEROD,NSBNC ,NCREEP,ATOLER,
  9   BTOLER,CTOLER,JPOST ,INTSTR,JBAND ,JFRONT,JDEFOR,NGMRS ,
  +   JEMBED,NBSECT,JDISP ,NSHIFT,NSUPER,JSUBRE,IFBFGS,NSPRI ,
  1   NDASH ,NMASS ,NSBFGS,IFSCNT,IFLINE,IFPRNT,NHARM ,NHEP  ,
  2   NMFBAN,NFBG  ,ICOMPS,NPDPTS,NPULSE,IPCONJ,NPSDS ,NPSDP ,
  3   NPSEP ,JXMODE,LDYN  ,JFDCOR,JISTIF,JCENTM,NHARD ,JFINIT,
  4   JLARGE,JFOLOW,JWKSLP,JISTRN,JCITER,JHRGLS,NDIMEN,JGRAM ,
  5   JPRES ,NMONIT,NBSPS ,NRNCOF)
C
C ***********************************************************************
C **                                                                  **
C **  READ THE PARAMETER DATA BLOCK AND SET MOST CONTROL
FLAGS      **
C **                                                                  **
C ***********************************************************************
C
C  ARGUMENTS:
C
C    RWORK    REAL WORKSPACE IN BLANK COMMON
C    IWORK    INTEGER WORKSPACE IN BLANK COMMON
C    ISIZE    SIZE OF INTEGER ARRAY IN BLANK COMMON
C    VERSNO   THE VERSION NUMBER FOR THIS CODE RELEASE
C    MONTH    THE MONTH IT WAS RELEASED
C    JDATE    THE DAY IT WAS RELEASED
C    NELEM    NUMBER OF ELEMENTS IN THE MESH
C    NNODE    NUMBER OF NODES IN THE MESH
C    NBC      NUMBER OF DISPLACEMENT BOUNDARY CONDITIONS
C    NTIE     NUMBER OF TYING CONSTRAINT EQUATIONS
C    NMAX     MAXIMUM NUMBER OF TERMS IN ONE TYING EQUATION
C    NTRAN    NUMBER OF NODES WITH COORDINATE TRANSFORMATIONS
C    NTRAC    NUMBER OF APPLIED POINT LOADS
C    NPOST
C    NLVSUB   SUBSTRUCTURE OPTION PARAMETERS (INACTIVE)
```

```
C   NFRSUB   SUBSTRUCTURE OPTION PARAMETERS (INACTIVE)
C   NEXT     SUBSTRUCTURE OPTION PARAMETERS (INACTIVE)
C   JDYN
C   JTEMP    TEMPERATURE LOADING FLAG
C   NPRINT
C   JREST    RESTART PROBLEM FLAG
C   JINC     THE CURRENT INCREMENT NUMBER
C   NINC     THE MAXIMUM INCREMENT NUMBER
C   JLOUB
C   JINTER
C   JEXTRA
C   JWEIGH
C   NSTRBC   NUMBER OF STRESS BOUNDARY CONDITIONS (AVOID THIS!)
C   NTYPE    NUMBER OF ELEMENT TYPES
C   MAXSUB   SUBSTRUCTURE OPTION PARAMETERS (INACTIVE)
C   ILAST    THE LAST ADDRESS, USED AS THE INPUT BUFFER
C   JSUB     SUBSTRUCTURE OPTION PARAMETERS (INACTIVE)
C   NSUB     SUBSTRUCTURE OPTION PARAMETERS (INACTIVE)
C   ISTAT    STATIC ANALYSIS FLAG
C   IDYNM    DYNAMIC ANALYSIS FLAG
C   ITEST    CODE TESTING FLAG (AVOID THIS ONE TOO!)
C   JOPTIM
C   JCREEP
C   JDIST
C   NONISO
C   NDYNMD
C   IDYNMD
C   NPOSMD
C   ITHERM
C   JCONST
C   NDUP
C   JREPOT
C   JTANGE
C   JTHERM   A FLAG FOR THE 'UTHERM' USER SUBROUTINE
C   DALPHA
C   DBETA
C   DGAMMA
C   JEIGEN   EIGENVALUE ANALYSIS FLAG
C   JFORCE   A FLAG FOR THE 'UFORCE' USER SUBROUTINE
C   JUTEMP   A FLAG FOR THE 'UTEMP' USER SUBROUTINE
C   JUCOEF   A FLAG FOR THE 'UCOEF' USER SUBROUTINE
C   JDISTS   A FLAG FOR THE 'UDIST' USER SUBROUTINE
C   JUHOOK   A FLAG FOR THE 'UHOOK' USER SUBROUTINE
C   JDERIV   A FLAG FOR THE 'UDERIV' USER SUBROUTINE
C   JUBOUN   A FLAG FOR THE 'UBOUN' USER SUBROUTINE
C   JPEROD   PERIODIC LOADING FLAGS (TWO INTEGERS)
```

```
C   NSBNC
C   NCREEP
C   ATOLER   TOLERANCE 'A' FOR ADAPTIVE CREEP ALGORITHM
C   BTOLER   TOLERANCE 'B' FOR ADAPTIVE CREEP ALGORITHM
C   CTOLER   TOLERANCE 'C' FOR ADAPTIVE CREEP ALGORITHM
C   JPOST
C   INTSTR
C   JBAND   A FLAG TO INVOKE THE PROFILE SOLVER (DEFAULT)
C   JFRONT   A FLAG TO ACTIVATE THE FRONTAL SOLVER
C   JDEFOR   A FLAG TO ACTIVATE THE DEFORMATION MODES OPTION
C   NGMRS   NUMBER OF GENERALIZED MODELING REGIONS (INACTIVE)
C   JEMBED   EMBEDDED SINGULARITIES FLAG (INACTIVE)
C   NBSECT   NUMBER OF BEAM SECTIONS (=NNODE)
C   JDISP   DISPLACEMENT METHOD FLAG
C   NSHIFT   NUMBER OF POWER SHIFTS IN THE EIGENVALUE SOLVER
C   NSUPER   NUMBER OF MODES USED FOR SUPERPOSITION
C   JSUBRE
C   IFBFGS   INVERSE B.F.G.S. RANK-TWO UPDATE FLAG
C   NSPRI   NUMBER OF ADDED GROUND SPRINGS
C   NDASH   NUMBER OF ADDED DASHPOTS (INACTIVE)
C   NMASS   NUMBER OF ADDED MASSES
C   NSBFGS   NUMBER OF B.F.G.S. VECTORS
C   IFSCNT   DAVIDON RANK-ONE SECANT NEWTON FLAG
C   IFLINE   LINE SEARCH ALGORITHM FLAG
C   IFPRNT
C   NHARM   NUMBER OF HARMONIC EXCITATIONS
C   NHEP   NUMBER OF HARMONIC EXCITATION POINTS
C   NMFBAN   NUMBER OF MACRO-FREQUENCY BANDS
C   NFBG   NUMBER OF FREQUENCY BAND GAUSS POINTS
C   ICOMPS
C   NPDPTS   NUMBER OF PULSE LOAD DATA POINTS
C   NPULSE   NUMBER OF PULSE LOADINGS
C   IPCONJ
C   NPSDS   NUMBER OF POWER SPECTRUM EXCITATIONS
C   NPSDP   NUMBER OF POWER SPECTRUM DATA POINTS
C   NPSEP   NUMBER OF POWER SPECTRUM EXCITATION POINTS
C   JXMODE   A FLAG TO INCLUDE CROSS-MODAL TERMS
C   LDYN   LINEAR DYNAMICS FLAG
C   JFDCOR   FREQUENCY-DEPENDENT CORRELATION FLAG
C   JISTIF   FIRST INCREMENT WITH INITIAL STRESS TERMS
C   JCENTM   FIRST INCREMENT WITH CENTRIFUGAL MASS EFFECTS
C   NHARD   NUMBER OF DATA POINTS FOR WORK-HARDENING CURVES
C   JFINIT   FIRST INCREMENT FOR FINITE STRAIN COMPUTATIONS
C   JLARGE   FIRST INCREMENT FOR LARGE DEFORMATION
COMPUTATIONS
C   JFOLOW   FIRST INCREMENT WITH FOLLOWER FORCE EFFECTS
```

```
C    JWKSLP   A FLAG FOR THE 'UWKSL' USER SUBROUTINE
C    JISTRN
C    JCITER
C    JHRGLS
C    NDIMEN   NUMBER OF SPACE DIMENSIONS
C    JGRAM
C    JPRES    NODAL PRESSURE FLAG
C    NMONIT   NUMBER OF QUANTITIES MONITORED BETWEEN
ITERATIONS
C    NBSPS    NUMBER OF BEAM SECTION PARAMETERS
C    NRNCOF   NUMBER OF USER-DEFINED RANDOM COEFFICIENTS
C    JFRAC    A FLAG FOR FRACTURE CALCULATIONS
C
C  NOTES:
C
C  * THIS SUBROUTINE IS CALLED BY:
C
C    FEM      TO READ IN THE PARAMETER DATA BLOCK IN THE INPUT FILE
C
C  * EQUIVALENCE STATEMENTS ARE USED TO BREAK-UP THE BIG ARRAY
'NAME'
C    INTO THREE NON-OVERLAPPING SEGMENTS 'NAME1', 'NAME2' AND
'NAME3'.
C    IN THIS WAY, WE CAN CONTINUE TO USE (MORE OR LESS) WELL
ALIGNED
C    DATA STATEMENTS TO FILL-IN THE CONTENTS OF THE ARRAY
WITHOUT
C    HITTING THE FORTRAN LIMIT FOR CONTINUATION LINES...
C
C  * TO ADD A NEW PARAMETER DATA OPTION, YOU SHOULD
C
C    A.  INCREMENT VARIABLE 'NOPT' BY ONE TO ACCOMODATE A NEW
OPTION
C    B.  ADD A UNIQUE KEYWORD FOR THAT OPTION IN THE 'NAME' ARRAY
C    C.  EXPAND THE COMPUTED GO TO STATEMENT WITH A NEW LINE
NUMBER
C    D.  ADD THE CODE TO READ THE INPUT, SET PARAMETERS, ETC. FOR
YOUR
C        NEW OPTION. YOU MAY WANT TO DO THIS IN A NEW SUBROUTINE
C    E.  TEST THE CODE YOU HAVE ADDED AND/OR MODIFIED!
C
C ********************************************************************
C
      IMPLICIT REAL*8 ( A-H , O-Z )
          REAL*4  RWORK
C
```

```
      DIMENSION RWORK ( ISIZE) ,IWORK ( ISIZE)
      DIMENSION NFRSUB(MAXSUB) ,NLVSUB(MAXSUB)
      DIMENSION NAME  ( 4, 74) ,NN    (     6)
      DIMENSION NAME1 ( 4, 34) ,NAME2 ( 4, 36)
      DIMENSION NAME3 ( 4,  5)
      DIMENSION JPEROD(     2)
C
      EQUIVALENCE (NAME( 1, 1),NAME1( 1, 1))
      EQUIVALENCE (NAME( 1,35),NAME2( 1, 1))
      EQUIVALENCE (NAME( 1,71),NAME3( 1, 1))
C
C ***********************************************************************
C
      COMMON / ALGEM  / ICREAD,ILPRNT,JLPRNT,ICONSL,IPOSTF,ISCRAF,
     1              IPLOTB,IRSTRT,JCREAD,IRVBIN,IDBASE,IRVDEF,
     2              PI    ,LINE  ,LINE2
      COMMON / COUNT  / LININC,LINTOT,NOECHO
      COMMON / CTITLE / TITLE (  20),IDAT  (     5),IDATE2,ICLOCK,
     1              IFCRAY
      COMMON / ERRORS / IERR
      COMMON / FREE   / IA    (  80),IBEGIN(  16),ILENGT(  16),
     1              NSTRIN,IS    ,ICOL  ,NEW
      PARAMETER (MRANV=100)
      COMMON /ZFDEFI/ ISMODL, IRMODL, NSVARS, NRVARS, IUZFUN,
     +          ISVARS(MRANV), IRVARS(MRANV),IROUTN
      LOGICAL NEW
C
C ***********************************************************************
C
      DATA NAME1
     *      /1HE,1HL,1HE,1HM, 1HN,1HO,1HD,1HE, 1HB,1HO,1HU,1HN,
     *       1HT,1HY,1HI,1HN, 1HT,1HR,1HA,1HN, 1HF,1HO,1HR,1HC,
     *       1HP,1HO,1HS,1HT, 1HS,1HU,1HB,1HS,
     *       1HE,1HX,1HT,1HE, 1HP,1HR,1HE,1HS, 1HT,1HE,1HM,1HP,
     *       1HP,1HR,1HI,1HN, 1HR,1HE,1HS,1HT, 1HL,1HO,1HU,1HB,
     *       1HS,1HT,1HR,1HE, 1HE,1HN,1HD,1H ,
     *       1HT,1HE,1HS,1HT, 1HD,1HY,1HN,1HA, 1HO,1HP,1HT,1HI,
     *       1HT,1HR,1HA,1HC, 1HC,1HR,1HE,1HE, 1HA,1HN,1HI,1HS,
     *       1HM,1HO,1HD,1HA, 1HB,1HU,1HC,1HK, 1HT,1HH,1HE,1HR,
     *       1HC,1HO,1HN,1HS, 1HD,1HI,1HS,1HT, 1HD,1HU,1HP,1HL,
     *       1HR,1HE,1HP,1HO, 1HT,1HA,1HN,1HG, 1HU,1HT,1HH,1HE,
     *       1HS,1HC,1HH,1HE, 1HU,1HF,1HO,1HR, 1HU,1HT,1HE,1HM/
      DATA NAME2
     *      /1HU,1HC,1HO,1HE, 1HU,1HD,1HI,1HS, 1HU,1HH,1HO,1HO,
     *       1HU,1HD,1HE,1HR, 1HU,1HB,1HO,1HU, 1HP,1HE,1HR,1HI,
     *       1HB,1HA,1HN,1HD, 1HF,1HR,1HO,1HN, 1HD,1HE,1HF,1HO,
```

```
     *       1HE,1HM,1HB,1HE, 1HG,1HM,1HR,1HS, 1HB,1HE,1HA,1HM,
     *       1HD,1HI,1HS,1HP, 1HS,1HH,1HI,1HF, 1HB,1HF,1HG,1HS,
     *       1HS,1HP,1HR,1HI, 1HD,1HA,1HS,1HH, 1HM,1HA,1HS,1HS,
     *       1HS,1HE,1HC,1HA, 1HL,1HI,1HN,1HE, 1HH,1HA,1HR,1HM,
     *       1HX,1HX,1HX,1HX, 1HC,1HO,1HM,1HP, 1HP,1HU,1HL,1HS,
     *       1HC,1HO,1HN,1HJ, 1HF,1HR,1HE,1HQ, 1HP,1HS,1HD,1H ,
     *       1HN,1HO,1HE,1HC, 1HP,1HE,1HR,1HT, 1HS,1HT,1HI,1HF,
     *       1HC,1HE,1HN,1HT, 1HH,1HA,1HR,1HD, 1HF,1HI,1HN,1HI,
     *       1HL,1HA,1HR,1HG, 1HF,1HO,1HL,1HL, 1HU,1HW,1HK,1HS/
      DATA NAME3
     *      /1HH,1HO,1HU,1HR, 1HM,1HO,1HN,1HI, 1HC,1HO,1HE,1HF,
     *       1HF,1HR,1HA,1HC, 1HX,1HX,1HX,1HX              /
C
C ******************************************************************
C
C   PARAMETER DATA OPTIONS
C   ====================
C    1       *ELEM MAXIMUM NUMBER AND THE TYPE OF ELEMENT
C    2       *NODE MAXIMUM NUMBER OF NODES
C    3       *BOUN MAXIMUM NUMBER OF DISPLACEMENT CONSTRAINT
C    4       *TYIN FLAG THE TYING OPTION WITH NUMBER OF TYING
C               DEGREE OF FREEDOMS
C    5       *TRAN COORDINATE TRANSFORMATION OPTION FLAGGED
WITH
C               THE NUMBER OF POINTS SUBJECTED TO THIS OPER.
C    6       *FORC MAXIMUM NUMBER OF NODAL FORCE DATA
C    7       *POST FLAG THE POST PROCCESSING TAPE GENERATION
C               OPTION
C    8       *SUBS FLAG THE SUBSTRUCTURING OPTION WITH THE
NUNBER
C               OF SUBSTRUCTURES
C    9       *EXTE
C   10       *PRES FLAG THE NODAL PRESSURE DEFINITION OPTION
C   11       *TEMP FLAG FOR THERMAL LOADING
C   12       *PRIN FLAG FOR PRINT OUTPUT
C   13       *REST FLAG FOR RESTART RUN
C   14       *LOUB SET UP NUMERICAL INTEGRATION
C   15       *STRE FLAG FOR STRESS BOUNDARY CONDITIONS
C   16       *END  .....OBVIOUS..............
C   17       *TEST (RESERVED)
C   18       *DYNA INVOKE TRANSIENT TIME INTEGRATION
C   19       *OPTI FLAG THE BAND-WIDTH OPTIMIZATION
C   20       *TRAC FLAG THE DISTRIBUTED LOADING
C   21       *CREE FLAG THE CREEP STRAIN OPTION
C   22       *ANIS FLAG ANISOTROPY OPTION
C   23       *MODA MODAL ANALYSIS OPTION
```

```
C  24     *BUCK BUCKLING ANALYSIS OPTION
C  25     *THER TEMPERATURE DEPENDENT ELASTICITY OPTION
C  26     *CONS CONSTITUTIVE EQUATION SELECTION
C  27     *DIST FLAG FOR DISTRIBUTED LOAD
C  28     *DUPL DUPLICATED NODE OPTION
C  29     *REPO REPORT GENERATION INTERVAL
C  30     *TANG MODIFIED NEWTON OPTION
C  31     *UTHE USER SUBROUTINE 'UTHERM' OPTION
C  32     *SCHE TIME INTEGRATION SCHEME OPTION
C  33     *UFOR USER SUBROUTINE 'UFORCE' OPTION
C  34     *UTEM USER SUBROUTINE 'UTEMP' OPTION
C  35     *UCOE USER SUBROUTINE 'UCOEF' OPTION
C  36     *UDIS USER SUBROUTINE 'UDIST' OPTION
C  37     *UHOO USER SUBROUTINE 'UHOOK' OPTION
C  38     *UDER USER SUBROUTINE 'UDERIV' OPTION
C  39     *UBOU USER SUBROUTINE 'UBOUN' OPTION
C  40     *PERI PERIODIC LOADING CONDITION OPTION FOR THE
C  41     *BAND PROFILE EQUATION SOLVER (DEFAULT)
C  42     *FRON FRONTAL SOLUTION SUBSYTEM (OPTIONAL)
C  43     *DEFO EIGENVALUE EXTRACTION FOR THE STIFFNESS
C  44     *EMBE SUBELEMENT MESH ANALYSIS OPTION
C  45     *GMRS MULTIPLE GENERIC MODELLING REGIONS OPTION
C  46     *BEAM BEAM SECTION PARAMETER OPTION
C  47     *DISP CONVENTIONAL DISPLACEMENT METHOD
C  48     *SHIF POWER SHIFT FOR EIGEN EXTRACTION
C  49     *BFGS BFGS UPDATE FOR THE NONLINEAR SOLUTION
C  50     *SPRI ADDED STIFFNESS, GROUND SPRING
C  51     *DASH ADDED DAMPING, DASHPOT TO GROUND
C  52     *MASS ADDED MASS
C  53     *SCEN SECANT NEWTON METHOD
C  54     *LINE LINE SEARCH
C  55     *HARM HARMONIC EXCITATION OPTION
C  56     *XXXX ...OPEN...
C  57     *COMP COMPOSITE LAMINATE OPTION FOR ELEMENT 75
C  58     *PULS PULSE LOAD OPTION
C  59     *CONJ CONJUGATE GRADIENT ITERATION
C  60     *SHOC SHOCK SPECTRA OPTION
C  61     *PSD  POWER SPECTRAL DENSITY OPTION
C  62     *NOEC SUPRESS THE MODEL DATA ECHO PRINT
C  63     *PERT SET UP PERTURBATION SIZE FLAGS
C  64     *STIF STRESS STIFFENING OPTION
C  65     *CENT CENTRIFUGAL MASS STIFFNESS OPTION
C  66     *HARD  WORK-HARDENING OPTION FOR PLASTICITY
C  67     *FINI FINITE STRAIN OPTION
C  68     *LARG LARGE DISPLACEMENTS & ROTATIONS OPTION
C  69     *FOLL FOLLOWER FORCES OPTION
```

```
C  70        *UWKS USER SUBROUTINE 'UWKSL'
C  71        *HOUR SPECIAL HOURGLASS CONTROL FLAG
C  72        *MONI INVOKES MONITOR UTILITY
C  73        *COEF USER-DEFINED RANDOM COEFFICIENTS
C  74        *FRAC SIGNALS FRACTURE CALCULATIONS, I.E. KI OPTION
C  75        *XXXX ...OPEN...
C
C **********************************************************************
C
      NOPT    =  75
      JSUBRE  =  0
      LOECHO  =  0
      IFPRNT  =  0
C
C **********************************************************************
C   SET DEFAULT VALUES
C **********************************************************************
C
      NSHIFT  =  0
      JPOST   =  0
      NSPRI   =  0
      NDASH   =  0
      NMASS   =  0
      NHARM   =  0
      NTIE    =  0
      NDUP    =  0
      JEMBED  =  0
      ITHERM  =  0
      NCREEP  =  1
      JEMBED  =  0
      JDISP   =  0
      JHRGLS  =  0
      JWKSLP  =  0
      JISTRN  =  0
      JCITER  =  0
      JREPOT  =  1
      ISTAT   =  1
      NSBFGS  =  0
      IDYNM   =  0
      NGMRS   =  1
      IPCONJ  =  0
      JSUB    =  0
      NSUB    =  0
      JFRONT  =  0
      JREST   =  0
      JCREEP  =  0
```

```
      JTEMP   =   0
      NEXT    =   0
      JUBOUN  =   0
      NONISO  =   0
      IFBFGS  =   0
      IFSCNT  =   0
      IFLINE  =   0
      NDYNMD  =   0
      IDYNMD  = 100000
      NPOSMD  =   0
      JTHERM  =   0
      JCONST  =   2
      JDYN    =   0
      JEIGEN  =   0
      JDEFOR  =   0
      NBSECT  =   0
      JFORCE  =   0
      JPEROD(1) =   0
      JPEROD(2) =   0
      JUTEMP  =   0
      JUCOEF  =   0
      JDISTS  =   0
      JUHOOK  =   0
      JDERIV  =   0
      JDIST   =   0
      JOPTIM  =   0
      JPEROD(1) =   0
      JPEROD(2) =   0
      ICOMPS  =   0
      NPDPTS  =   0
      NPULSE  =   0
      JFDCOR  =   0
      JISTIF  = 999999
      JCENTM  = 999999
      JFINIT  = 999999
      JLARGE  = 999999
      JFOLOW  = 999999
      NBSPS   =   0
      IFSPEC  =   0
      NRNCOF  =   0
      JFRAC   =   0
C
C ***********************************************************************
C   READ TITLE CARD AND PRINT THE USUAL PROBLEM HEADER
C ***********************************************************************
C
```

```
      READ(ICREAD,1000,END=3001) TITLE
 1000 FORMAT(20A4)
      C
C     CALL HEAD                                   HOST
C    1    (VERSNO,MONTH ,JDATE ,ILPRNT,ICONSL)              HOST
      IF(ISMODL.EQ.2) THEN
        CALL HEADER
     1    (VERSNO,MONTH ,JDATE ,ILPRNT,ICONSL, 8 )
      ELSE
        CALL HEADER
     1    (VERSNO,MONTH ,JDATE ,ILPRNT,ICONSL, 2 )
      END IF
      CALL LINES(70,0)
      WRITE(ILPRNT,1001) TITLE
 1001 FORMAT(10X,20A4)
      NEW = .TRUE.
C
C ********************************************************************
C     READ THE PARAMETER DATA CARDS
C ********************************************************************
C
 998 CONTINUE
C
C ... CALL THE KEYWORD INTERPRETER
C
      CALL KEY( NAME , NOPT , IOPT , NN , 6 , IERR  )
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
     &    22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,
     &    41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,
     &    60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75), IOPT
C
C ********************************************************************
C     OPTION 1 : *ELEM  - MAXIMUM NUMBER OF ELEMENTS IN MODEL
C     ---------------------------------------------------
C
   1 CONTINUE
                  NELEM = NN(1)
      CALL TYPEIN
     1    (IWORK ,RWORK ,IERR  ,NTYPE ,ILAST ,ILPRNT,NDIMEN)
      GO TO 998
C
C ********************************************************************
C     OPTION 2 : *NODE - MAXIMUM NUMBER OF NODES IN MODEL
C     ----------------------------------------------
C
```

```
  2 CONTINUE
                NNODE = NN(1)
   GO TO 998
C
C ********************************************************************
C   OPTION 3 : *BOUN - MAXIMUM NUMBER OF BOUNDARY CONDITIONS
C   ----------------------------------------------------
C
  3 CONTINUE
                NBC   = NN(1)
   GO TO 998
C
C ********************************************************************
C   OPTION 4 : *TYIN - MAXIMUM NUMBER OF TYING CONSTRAINTS
C   --------------------------------------------------
C
  4 CONTINUE
   NTIE  = NN(1)
   NMAX  = NN(2)
   GO TO 998
C
C ********************************************************************
C   OPTION 5 : *TRAN - NUMBER OF NODAL COORDINATE
TRANSFORMATIONS
C   ---------------------------------------------------------
C
  5 CONTINUE
   NTRAN = NN(1)
   GO TO 998
C
C ********************************************************************
C   OPTION 6 : *FORC - MAXIMUM NUMBER OF NODAL FORCE ENTRIES
C   ----------------------------------------------------
C
  6 CONTINUE
   NTRAC = NN(1)
   GO TO 998
C
C ********************************************************************
C   OPTION 7 : *POST - POST PROCESSING FILE GENERATION
C   -----------------------------------------------
C
  7 CONTINUE
   JPOST = 1
   NPOST = 1
   IF (NN(1).GT.0) NPOST = NN(1)
```

```
      GO TO 998
C
C ************************************************************************
C    OPTION 8 : *SUBS - SUBSTRUCTURE INPUT (INACTIVE)
C    -----------------------------------------
C
    8 CONTINUE
      JSUB = NN(1)
      NSUB = NN(2)
      IF(JSUB.NE.2) GO TO 998
      DO 108 J = 1,NSUB
      CALL FREFOR(NN,NN,3,0,0,IERR,JKEY)
      NLVSUB(NN(1)) = NN(2)
      NFRSUB(NN(1)) = NN(3)
  108 CONTINUE
      GO TO 998
C
C ************************************************************************
C    OPTION 9 : *NEXT - EXTERNAL D.O.F. (INACTIVE)
C    ------------------------------------
C
    9 CONTINUE
      NEXT = NN(1)
      GO TO 998
C
C ************************************************************************
C    OPTION 10 : *PRES - NODAL PRESSURE DEFINITION
C    --------------------------------------------------
C
   10 CONTINUE
      JPRES = 1
      GO TO 998
C
C ************************************************************************
C    OPTION 11 : *TEMP - TEMPERATURE LOAD FLAG TO BE SET
C    -------------------------------------------------------
C
   11 CONTINUE
      JTEMP = 1
      GO TO 998
C
C ************************************************************************
C    OPTION 12 : *PRIN - INCREASE THE NUMBER OF PRINT OPTIONS
C    -------------------------------------------------------------
C
   12 CONTINUE
```

```
      IF (NN(1).LT.0) IFPRNT = 1
      IF (NN(1).LT.0) NPRINT = IABS(NN(1))
      IF (NN(1).GT.0) NPRINT = NN(1)
      GO TO 998
C
C **********************************************************************
C   OPTION 13 : *REST - THIS IS A RESTART PROBLEM
C   ---------------------------------------------
C
   13 CONTINUE
      JREST = 1
C
C ... THEN EXIT IMMEDIATELY WITHOUT READING THE *END CARD
C
      GO TO 16
C
C **********************************************************************
C   OPTION 14 : *LOUB - SELECTS NUMERICAL QUADRATURE RULES
C   -----------------------------------------------------
C
   14 CONTINUE
      JLOUB = 1
      JINTER = NN(1)
      JEXTRA = NN(2)
      JWEIGH = NN(3)
      JGRAM  = NN(4)
      IF(JINTER.LT.1.OR.JINTER.GT.4) JINTER = 2
      IF(JEXTRA.LT.1.OR.JEXTRA.GT.3) JEXTRA = 1
      IF(JWEIGH.LT.1.OR.JWEIGH.GT.5) JWEIGH = 1
      IF(JGRAM .LT.0.OR.JGRAM .GT.1) JGRAM  = 0
C
C ... SPECIAL TRICKS FOR INITIAL STRAIN AND CONSISTENT MASS
ITERATION
C
C     IF( NN( 6 ) .NE. 0 )  JISTRN = 1
      IF( NN( 5 ) .NE. 0 )  JCITER = NN( 5 )
      GO TO 998
C
C **********************************************************************
C   OPTION 15 : *STRE - MAXIMUM NUMBER OF STRESS BOUNDARY
CONDITIONS
C   ----------------------------------------------------------------
C
   15 CONTINUE
      NSTRBC = NN(1)
      GO TO 998
```

```
C
C ************************************************************************
C    OPTION 17 : *TEST - FOR INTERNAL USE OF THE MARC DEVELOPMENT
TEAM
C    ----------------------------------------------------------------
C                    ... THIS IS AN EXTREMELY DANGEROUS OPTION ...
C
  17 CONTINUE
     ISTAT  =  0
     IDYNM  =  0
     ITEST  =  1
     GO TO 998
C
C ************************************************************************
C    OPTION 18 : *DYNA - TRANSIENT TIME INTEGRATION PARAMETERS
C    -------------------------------------------------------
C
  18 CONTINUE
     JDYN   = NN( 1 )
     IF(JDYN .LE. 0) JDYN   = 1
     IF(JDYN .GT. 2) JDYN   = 2
     ISTAT  =  0
     IDYNM  =  1
     ITEST  =  0
     GO TO 998
C
C ************************************************************************
C    OPTION 19 : *OPTI - BANDWIDTH OPTIMIZER ITERATION CYCLES
C    -------------------------------------------------------
C
  19 CONTINUE
     JOPTIM = NN(1)
     IF(JOPTIM.EQ.0) JOPTIM=10
     GOTO 998
C
C ************************************************************************
C    OPTION 20 : *TRAC - DUMMY - SAME AS THE *DIST OPTION
C    ---------------------------------------------------
C
  20 CONTINUE
     JDIST = 1
     GO TO 998
C
C ************************************************************************
C    OPTION 21 : *CREE - CREEP AND ITS TIME STEP CONTROL PARAMETERS
C    -------------------------------------------------------------
```

```
C
  21 CONTINUE
     JCREEP = 1
     NCREEP = 3
     ATOLER = 0.5D0
     BTOLER = 0.5D-1
     CTOLER = 0.5D-1
C
     IF( NN( 1 ) .EQ. 0 ) GO TO 2101
C
     NCREEP = NN( 1 )
C
     CALL FREFOR
    1    ( IWORK(ILAST+1) , RWORK(ILAST+1) , 0 , 3 , 0 , IERR , JKEY )
C
           J = ILAST + 1
     IF( RWORK(J) .NE. 0.0 ) CALL COPYSD ( RWORK(J) , ATOLER , 1 )
           J = ILAST + 2
     IF( RWORK(J) .NE. 0.0 ) CALL COPYSD ( RWORK(J) , BTOLER , 1 )
           J = ILAST + 3
     IF( RWORK(J) .NE. 0.0 ) CALL COPYSD ( RWORK(J) , CTOLER , 1 )
C
 2101 CONTINUE
     GO TO 998
C
C *******************************************************************
C    OPTION 21 : *ANIS - ANISOTROPIC ELASTICITY
C    ------------------------------------------
C
 22  CONTINUE
     NONISO=1
     GO TO 998
C
C *******************************************************************
C    OPTION 23 : *MODAL - MODAL ANALYSIS OPTION AND PARAMETER
SET
C    -----------------------------------------------------------
C
 23  NDYNMD=NN(1)
C    The next statement modified by RAJ 10/31/94
C
C    NSBNC =NN(2)
     IUSER = NN(2)
C
     INTSTR=NN(3)
     IF ( NDYNMD .EQ. 0 )    NDYNMD =  1
```

```
C
C   The following three statements were modified due to the convergence
C   difficulties while running hex vane problem 10/31/94
C   IF ( NSBNC  .EQ. 0 )    NSBNC  =  NDYNMD * 2
C                   MDYNMD =  NDYNMD + 8
C   IF ( NSBNC  .GT. MDYNMD) NSBNC  = MDYNMD
C
      ITEMP1 = NDYNMD + 8
      ITEMP2 = NDYNMD * 2
      IMIN   = MIN0(ITEMP1,ITEMP2)
      IMAX   = MAX0(ITEMP1,ITEMP2)
      IF (IUSER.LE.0) NSBNC = IMIN
      IF (IUSER.GT.0) NSBNC = MIN0(IUSER,IMAX)
                 JEIGEN = 1
                 LDYN   = 1
                 IDYNM  = 1
                 ISTAT  = 0
C
      CALL NULINT(NN,4)
      JKEY = 0
      CALL FREFOR(NN,NN,1,0,0,IERR,JKEY)
      IF ( JKEY .EQ. 1 ) GO TO 998
      NSUPER = NN(1)
C
                 LDYN   = 2
      GO TO 998
C
C *********************************************************************
C   OPTION 24 : *BUCK - BUCKLING ANALYSIS AND PARAMETERS
C   ---------------------------------------------------
C
   24 NDYNMD = NN(1)
      NSBNC  = NN(2)
      INTSTR = NN(3)
C
      IF( NDYNMD .EQ. 0 )    NDYNMD = 1
      IF( NSBNC  .EQ. 0 )    NSBNC  = 2 * NDYNMD
                   MSBNC  = 8 + NDYNMD
                   NSBNC  = MIN0( NSBNC,MSBNC )
C
                 ISTAT  = 1
                 IDYNM  = 0
                 JEIGEN = 1
      GO TO 998
C
C *********************************************************************
```

```
C   OPTION 25 : *THER - TEMPERATURE DEPENDENT PROPERTIES
C   ------------------------------------------------
C
 25 CONTINUE
    ITHERM = 1
    GO TO 998
C
C ********************************************************************
C   OPTION 25 : *CONS - CONSTITUTIVE LAW SELECTION
C   -------------------------------------------
C
 26 CONTINUE
                        JCONST = NN(1)
    IF(JCONST.LT.0.OR.JCONST.GT.4) JCONST = 2
    GO TO 998
C
C ********************************************************************
C   OPTION 27 : *DIST - ELEMENT DISTRIBUTED LOADS
C   ------------------------------------------
C
 27 CONTINUE
    JDIST=1
    GOTO 998
C
C ********************************************************************
C   OPTION 28 : *DUPL - MAXIMUM NUMBER OF DUPLICATE NODES
C   ------------------------------------------------
C
 28 CONTINUE
    NDUP=NN(1)
    GOTO 998
C
C ********************************************************************
C   OPTION 29 : *REPO - REPORT GENERATION INTERVAL TO BE SET
C   ---------------------------------------------------
C
 29 CONTINUE
    JREPOT = NN( 1 )
    IF(NN( 1 ) .EQ. 0) JREPOT=1
    GO TO 998
C
C ********************************************************************
C   OPTION 30 : *TANG - MODIFIED NEWTON METHOD WITH TANGENT
MATRIX
C              SPECIFICATION
C   -------------------------------------------------------------
```

```
C
 30 CONTINUE
   JTANGE = NN( 1 )
   GO TO 998
C
C ********************************************************************
C   OPTION 31 : *UTHE - ACTIVATES THE 'UTHERM' USER SUBROUTINE
C   -------------------------------------------------------
C
 31 CONTINUE
   JTHERM = 1
   GO TO 998
C
C ********************************************************************
C   OPTION 32 : *SCHE - TIME STEPPING SCHEME PARAMETER OPTIONS
C   -------------------------------------------------------
C
 32 CONTINUE
   DALPHA = 0.5D0
   DBETA  = 0.25D0
   DGAMMA = 0.5D0
   CALL FREFOR(IWORK(ILAST+1),RWORK(ILAST+1),0,3,0,IERR,JKEY)
   CALL COPYSD (RWORK(ILAST+1),DALPHA,1)
   CALL COPYSD (RWORK(ILAST+2),DBETA ,1)
   CALL COPYSD (RWORK(ILAST+3),DGAMMA,1)
   GO TO 998
C
C ********************************************************************
C   OPTION 33 : *UFOR - ACTIVATES THE 'UFORCE' USER SUBROUTINE
C   -------------------------------------------------------
C
 33 CONTINUE
   JFORCE = 1
   GO TO 998
C
C ********************************************************************
C   OPTION 34 : *UTEM - ACTIVATES THE 'UTEMP' USER SUBROUTINE
C   -------------------------------------------------------
C
 34 CONTINUE
   JUTEMP = 1
   GO TO 998
C
C ********************************************************************
C   OPTION 35 : *UCOE - ACTIVATES THE 'UCOEF' USER SUBROUTINE
C   -------------------------------------------------------
```

```
C
  35 CONTINUE
     JUCOEF = 1
     GO TO 998
C
C *****************************************************************
C   OPTION 36 : *UDIS - ACTIVATES THE 'UDIST' USER SUBROUTINE
C   -----------------------------------------------------
C
  36 CONTINUE
     JDISTS = 1
     GO TO 998
C
C *****************************************************************
C   OPTION 37 : *UHOO - ACTIVATES THE 'UHOOK' USER SUBROUTINE
C   -----------------------------------------------------
C
  37 CONTINUE
     JUHOOK = 1
     GO TO 998
C
C *****************************************************************
C   OPTION 38 : *UDER - ACTIVATES THE 'UDERIV' USER SUBROUTINE
C   ------------------------------------------------------
C
  38 CONTINUE
     JDERIV = 1
     GO TO 998
C
C *****************************************************************
C   OPTION 33 : *UBOU - ACTIVATES THE 'UBOUND' USER SUBROUTINE
C   ------------------------------------------------------
C
  39 CONTINUE
     JUBOUN = 1
     GO TO 998
C
C *****************************************************************
C   OPTION 40 : *PERI - PERIODIC LOADING FOR TRANSIENT DYNAMICS
C   -------------------------------------------------------
C
  40 CONTINUE
     JPEROD( 1 ) = NN( 1 )
     JPEROD( 2 ) = NN( 2 )
     GO TO 998
C
```

```
C ************************************************************************
C    OPTION 41 : *BAND - PROFILE EQUATION SOLVER (A MISNOMER)
C    --------------------------------------------------------
C
  41 CONTINUE
          JBAND  = 1
          JFRONT = 0
    GO TO 998
C
C ************************************************************************
C    OPTION 42 : *FRON - FRONTAL SOLUTION OPTION FOR STATIC
ANALYSIS
C    ----------------------------------------------------------------
C
  42 CONTINUE
          JBAND  = 0
          JFRONT = 1
    GO TO 998
C
C ************************************************************************
C    OPTION 43 : *DEFO - DEFORMATION MODE ANALYSIS
C    ---------------------------------------------
C
  43 CONTINUE
          JDEFOR = 1
          IDYNMD = NN( 1 )
          NDYNMD = NN( 2 )
          NSBNC  = NN( 3 )
          INTSTR = NN( 4 )
C
    IF ( NDYNMD .EQ. 0 ) NDYNMD = 1
                NSBNC  = 2 * NDYNMD
C
                MSBNC  = 8 + NDYNMD
    IF ( NDYNMD .GT. 8 ) NSBNC  = MSBNC
C
                ISTAT  = 1
                IDYNM  = 0
                JEIGEN = 1
    GO TO 998
C
C ************************************************************************
C    OPTION 44 : *EMBE - EMBEDDED SINGULARITIES (INACTIVE IN NESSUS)
C    ------------------------------------------
C
  44 CONTINUE
```

```
              JEMBED  =  1
   IF( NN( 1 ) .NE. 0 )   JSUBRE  =  1
C
   GO TO 998
C
C ***********************************************************************
C   OPTION 45 : *GMRS - GENERIC MODELING REGIONS (INACTIVE IN
NESSUS)
C   ------------------------------------------
C
 45 CONTINUE
              NGMRS = NN( 1 )
   IF( NGMRS .EQ. 0 ) NGMRS =  1
   GO TO 998
C
C ***********************************************************************
C   OPTION 46 : *BEAM - MAXIMUM NUMBER OF BEAM SECTION DATA
C   -----------------------------------------------------
C
 46 CONTINUE
              NBSPS = NN( 1 )
   IF ( NBSPS .EQ. 0 ) NBSPS =  6
   GO TO 998
C
C ***********************************************************************
C   OPTION 47 : *DISP - DISPLACEMENT METHOD OPTION
C   --------------------------------------------
C
 47 CONTINUE
        JDISP  = 1
   GO TO 998
C
C ***********************************************************************
C   OPTION 48 : *SHIF - POWER SHIFT FOR DYNAMIC EIGENVALUE
ANALYSIS
C   ------------------------------------------------------------
C
 48 CONTINUE
              NSHIFT = NN( 1 )
   IF( NSHIFT .EQ. 0 ) NSHIFT =    1
   GO TO 998
C
C ***********************************************************************
C   OPTION 49 : *BFGS - INVERSE BFGS RANK TWO UPDATE
C   ---------------------------------------------
C
```

```
 49 CONTINUE
                IFBFGS =  1
                NSBFGS =  10
    IF( NN(1) .NE. 0 )  NSBFGS = NN( 1 )
    GO TO 998
C
C ***********************************************************************
C    OPTION 50 : *SPRI - ADDED STIFFNESS, GROUND SPRING
C    ---------------------------------------------------
C
 50 CONTINUE
                NSPRI  = NN(1)
    IF ( NSPRI .EQ. 0 ) NSPRI  =    1
    GO TO 998
C
C ***********************************************************************
C    OPTION 51 : *DASH - ADDED DAMPING, DASHPOT TO GROUND
(INACTIVE)
C    ----------------------------------------------------
C
 51 CONTINUE
                NDASH  = NN(1)
    IF ( NDASH .EQ. 0 ) NDASH  =    1
    GO TO 998
C
C ***********************************************************************
C    OPTION 52 : *MASS - ADDED MASS, LUMPED WEIGHTS
C    ----------------------------------------------
C
 52 CONTINUE
                NMASS  = NN(1)
    IF ( NMASS .EQ. 0 ) NMASS  =    1
    GO TO 998
C
C ***********************************************************************
C    OPTION 53 : *SECA - DAVIDON RANK ONE SECANT NEWTON UPDATE
C    --------------------------------------------------------
C
 53 CONTINUE
                IFSCNT   =  1
    GO TO 998
C
C ***********************************************************************
C    OPTION 54 : *LINE - LINE SEARCH OPTION
C    --------------------------------------
C
```

```
 54 CONTINUE
          IFLINE  =  1
   GO TO 998
C
C *********************************************************************
C   OPTION 55 : *HARM - HARMONIC NODAL FORCE LOADING
C   ---------------------------------------------
C
 55 CONTINUE
   NHARM  = NN(1)
   NHEP   = NN(2)
   IF (NHARM .EQ. 0) NHARM  = 1
   IF (NHEP  .EQ. 0) NHEP   = 1
   IFSPEC = 1
   GO TO 998
C
C *********************************************************************
C   OPTION 56 : ...OPEN...
C   -----------
C
 56 CONTINUE
   GO TO 998
C
C *********************************************************************
C   OPTION 57 : *COMP - COMPOSITE LAMINATE OPTION
C   --------------------------------------------
C
 57 CONTINUE
             ICOMPS  =  1
   CALL COMPDF
  1   (IWORK ,RWORK ,IERR  ,NTYPE ,ILAST ,ILPRNT)
C
   GO TO 998
C
C
C *********************************************************************
C   OPTION 58 : *PULS - PULSE LOAD OPTION
C   ------------------------------------
C
 58 CONTINUE
   NPDPTS = NN(1)
   NPULSE = NN(2)
   IF (NPDPTS .LT. 2) NPDPTS = 2
   IF (NPULSE .EQ. 0) NPULSE = 1
   GO TO 998
C
```

```
C ********************************************************************
C    OPTION 59 : *CONJ - PRECONDITIONED CONJUGATE GRADIENT
ITERATION
C    -----------------------------------------------------------
C
  59 CONTINUE
          IPCONJ    =    1
          IFLINE    =    1
     GO TO 998
C
C ********************************************************************
C    OPTION 60 : *FREQ - FREQUENCY BAND INTEGRATION PARAMETERS
FOR
C              RANDOM VIBRATION IN THE FREQUENCY DOMAIN
C    -----------------------------------------------------------
C
  60 CONTINUE
     NMFBAN = NN(1)
     NFBG   = NN(2)
     IF (NMFBAN.EQ. 0) NMFBAN = 1
     IF (NFBG  .EQ. 0) NFBG   = 5
     JXMODE = NN(3)
     JFDCOR = NN(4)
     GO TO 998
C
C ********************************************************************
C    OPTION 61 : *PSD  - POWER SPECTRAL DENSITY OPTION
C    ----------------------------------------------
C
  61 CONTINUE
     NPSDS  = NN(1)
     NPSEP  = NN(2)
     NPSDP  = NN(3)
     IF (NPSDS .EQ. 0) NPSDS  = 1
     IF (NPSEP .EQ. 0) NPSEP  = 1
     IF (NPSDP .EQ. 0) NPSDP  = 2
     IFSPEC = 1
     GO TO 998
C
C ********************************************************************
C    OPTION 62 : *NOEC - SUPPRESS ECHO PRINT OUT OF THE MODEL DATA
C    -----------------------------------------------------------
C
  62 CONTINUE
     LOECHO = 1
     GO TO 998
```

```
C
C ***********************************************************************
C   OPTION 63 : *PERT - SET UP PERTURBATION FLAGS
C   --------------------------------------------
C
  63 CONTINUE
    CALL PERSIZ( NN(1), IERR )                                 NESSUS
    GO TO 998
C
C ***********************************************************************
C   OPTION 64 : *STIF - STRESS STIFFENING OPTION
C   --------------------------------------------
C
  64 CONTINUE
    JISTIF = NN(1)
    IF (JISTIF .EQ. 0) JISTIF = 1
    GO TO 998
C
C ***********************************************************************
C   OPTION 65 : *CENT - CENTRIFUGAL MASS SOFTENING OPTION
C   ----------------------------------------------------
C
  65 CONTINUE
    JCENTM = NN(1)
    GO TO 998
C
C ***********************************************************************
C   OPTION 66 : *HARD - WORK-HARDENING OPTION FOR PLASTICITY
C   -------------------------------------------------------
C
  66 CONTINUE
    NHARD = NN(1)
    IF (NHARD  .EQ. 0) NHARD  = 1
    GO TO 998
C
C ***********************************************************************
C   OPTION 67 : *FINIT - FINITE STRAIN OPTION
C   -----------------------------------------
C
  67 CONTINUE
    JFINIT = NN(1)
    GO TO 998
C
C
************************************************************************
C   OPTION 68 : *LARG - LARGE DISPLACEMENTS AND ROTATIONS OPTION
```

```
C    -------------------------------------------------------------
C
 68 CONTINUE
   JLARGE = NN(1)
   GO TO 998
C
C
***********************************************************************
C   OPTION 69 : *FOLL - FOLLOWER FORCE OPTION
C   ------------------------------------
C
 69 CONTINUE
   JFOLOW = NN(1)
   GO TO 998
C
C ***********************************************************************
C   OPTION 70 : *UWKS - FLAGS THE USER SUBROUTINE FOR
WORKHARDENING
C   ---------------------------------------------------------------
C
 70 CONTINUE
   JWKSLP = 1
   GO TO 998
C
C ***********************************************************************
C   OPTION 71 : *HOUR - HOURGLASS CONTROL FLAG IN A SPECIAL WAY
C   ----------------------------------------------------------
C
 71 CONTINUE
   JHRGLS  =  1
   GO TO 998
C
C ***********************************************************************
C   OPTION 72 : *MONI - TURN ON THE MONITOR UTILITY
C   ----------------------------------------------
C
 72 CONTINUE
   NMONIT = NN(1)
   IF (NMONIT .LT. 1) NMONIT = 1
   GO TO 998
C
C ***********************************************************************
C   OPTION 73 : *COEF - USER-DEFINED RANDOM COEFFICIENTS
C   ---------------------------------------------------
C
 73 CONTINUE
```

```
      NRNCOF = NN(1)
      GO TO 998
C
C *********************************************************************
C    OPTION 74 : *FRAC - SIGNALS KI CALCULATIONS
C    -----------
C
   74 CONTINUE
      JFRAC  =  1
      GO TO 998
C
C *********************************************************************
C    OPTION 75 : ...OPEN...
C    -----------
C
   75 CONTINUE
      GO TO 998
C
C *********************************************************************
C    NORMAL EXIT ROUTE AFTER READING THE *END CARD
C *********************************************************************
C
   16 CONTINUE
      IF (LOECHO .NE. 0) NOECHO = 1
C
C *********************************************************************
C    POSSIBLE CONTRADICTIONS IN PARAMETER DATA ARE CHECKED
HERE
C *********************************************************************
C
      IF( IFBFGS .EQ. 1 .AND. IFSCNT .EQ. 1 ) THEN
       CALL LINES( 2, 2 )
       WRITE(ILPRNT,6020) 'BFGS','SECA'
       WRITE(ICONSL,6020) 'BFGS','SECA'
       IERR = IERR+1
      ENDIF
C
      IF( IFBFGS .EQ. 1 .AND. IPCONJ .EQ. 1 ) THEN
       CALL LINES( 2, 2 )
       WRITE(ILPRNT,6020) 'BFGS','CONJ'
       WRITE(ICONSL,6020) 'BFGS','CONJ'
       IERR = IERR+1
      ENDIF
C
      IF( IPCONJ .EQ. 1 .AND. IFSCNT .EQ. 1 ) THEN
       CALL LINES( 2, 2 )
```

```
      WRITE(ILPRNT,6020) 'CONJ','SECA'
      WRITE(ICONSL,6020) 'CONJ','SECA'
      IERR = IERR+1
     ENDIF
C
     IF( JFINIT.LT.JLARGE              ) CALL QUIT
    &   ('*FIN','I ST','ARTS',' B4 ','*LAR','GE  ', 0 )
C
     IF( JLARGE.EQ.999999 )              T H E N
     IF( JFOLOW.NE.999999               ) CALL QUIT
    &   ('*FOL','L BU','T NO','*LAR','G   ','    ', 0 )
     IF( JFINIT.NE.999999 )             CALL QUIT
    &   ('*FIN','I BU','T NO','*LAR','G   ','    ', 0 )
                                  E N D I F
C
     IF( JLARGE.NE.999999 .AND. JISTIF.EQ.999999 ) CALL PRWARN
    & ( 'LARGE DISPL OPTION WITHOUT INITIAL STRESS OPTION')
C
     IF( NBSPS .GT. 0 ) NBSECT = NNODE
C
     IF( IFSPEC .GT. 0 ) THEN
      IF( NSUPER .GT. 0 ) THEN
       LDYN = 4
      ELSE
       CALL LINES( 2, 2 )
       WRITE(ILPRNT,6040) 'MODA'
       WRITE(ICONSL,6040) 'MODA'
       IERR = IERR+1
      ENDIF
     ENDIF
C
C ***********************************************************************
C    CHECK FOR PARAMETER DATA ERRORS BEFORE EXIT
C ***********************************************************************
C
     IF (IERR .GT. 0) GO TO 3002
C
C ... NORMAL EXIT FROM PARAMETER DATA READER
C
     RETURN
C
C ... STOP DUE TO PARAMETER DATA ERRORS
C
 3001 CONTINUE
     IERR = IERR + 1
     WRITE(ICONSL,9000)
```

```
 3002 CONTINUE
    CALL QUIT('PARA','METE','R DA','TA I','NPUT','    ', IERR )
    STOP
C
C *** FORMAT STATEMENTS
**********************************************
C
 6000 FORMAT( /,1X,'***ERROR***    OPTION ',I2,'  *',A4,' NOT ACTIVE')
 6020 FORMAT( /,1X,'***ERROR***    OPTION *',A4,' AND *',A4,' CANNOT',
    1          ' BE USED TOGETHER'                    )
 6040 FORMAT( /,1X,'***ERROR***    OPTION *',A4,' MUST BE SPECIFIED ',
    1          'WITH THIS TYPE OF ANALYSIS'             )
 9000 FORMAT(//,1X,'***ERROR***    END-OF-FILE WHILE READING INPUT',/)
C
    END
SUBROUTINE SETGFF
   1  (GFF   ,TNM   ,COOR  ,OMEGA ,NSUPER,NNODE ,MAXCRD,JPSD  )
C
C *********************************************************************
C **                                          **
C **  COMPUTES THE SPECTRAL DENSITY FOR THE MODAL FORCING
FUNCTION    **
C **                                          **
C *********************************************************************
C
C  PARAMETERS:
C
C   GFF     SPECTRAL DENSITY OF MODAL FORCING FUNCTION
C   TNM     TRANSFORMATION FROM NODAL TO MODAL BASIS
C   COOR    NODAL COORDINATE ARRAY
C   OMEGA   P.S.D. EXCITATION FREQUENCY
C   NSUPER  NUMBER OF EIGENVECTORS FOR MODE SUPERPOSITION
C   NNODE   TOTAL NUMBER OF NODES IN THE MODEL
C   MAXCRD  MAXIMUM NUMBER OF COORDINATES AT A NODE
C   JPSD    P.S.D. EXCITATION NUMBER
C
C  NOTES:
C
C  * THIS SUBROUTINE IS CALLED BY:
C
C   FREDOM   TO CONSTRUCT THE ONE-SIDED SPECTRAL DENSITY
FUNCTION
C          FOR THE FORCING TERM OF THE P.S.D EXCITATION
C
C  * THE ONE-SIDED SPECTRAL DENSITY FUNCTION FOR THE FORCING
TERM
```

```
C    OF THE P.S.D. EXCITATION IS DEFINED AS
C
C    G  (w) = T   T   rho  (w) psd(w)
C     mn       im  jn    ij
C
C    WHERE
C
C    T   = phi   fbar        (NO SUM ON i)
C     im      im     i
C
C  * IN THIS SUBROUTINE WE COMPUTE
C    _
C    G  (w) = T   T   rho  (w)
C     mn       im  jn    ij
C
C    WHICH IS THEN MULTIPLIED BY psd(w) IN THE CALLING ROUTINE TO
C    OBTAIN THE ACTUAL VALUE FOR THE SPECTRAL DENSITY
C            _
C    G  (w) = G  (w) psd(w)
C     mn       mn
C
C    IN THIS WAY, IF THE CORRELATION IS NOT FREQUENCY-DEPENDENT,
THE
C              _
C    TERMS IN G   NEED NOT BE RECOMPUTED AT EVERY INTEGRATION
POINT
C             mn
C
C **********************************************************************
C
      IMPLICIT REAL*8 ( A-H , O-Z )
C
      DIMENSION GFF ( NSUPER , NSUPER , 2 ), TNM ( NNODE  , NSUPER )
      DIMENSION COOR( MAXCRD , NNODE      ), RHO ( 2 )
c      save icall
c      data icall /19/
C
C **********************************************************************
C
      CALL NUL( GFF , NSUPER*NSUPER*2 )
      iw = 169
c      if(icall.eq.19) then
c        icall = 7
c        write (iw,*) 'TNM(nnode,nsuper)'
c        do 1001 i=1,nnode
c          write (iw,601) (tnm(i,j),j=1,nsuper)
```

```
c1001   continue
c601    format(1x,1p8e16.8)
c     endif
C
c**
c*  Must add an array containing the node id's that has excitation
c*  so that node id's that are not affected can be excluded properly
c*  tnm(i,1) is in general not a proper indicator, but is used for the hextv
c**
      DO 400 NODEI = 1, NNODE
       IF (TNM(NODEI,1) .EQ. 0.00D0) GO TO 400
       DO 200 NODEJ = 1, NNODE
        IF (TNM(NODEJ,1) .EQ. 0.00D0) GO TO 200
C
C ... EVALUATE THE CORRELATION COEFFICIENT
C
        CALL
UPSRHO(RHO,NODEI,NODEJ,COOR,NNODE,MAXCRD,OMEGA,JPSD)
c         write (iw,*) 'nodei,nodej:',nodei,nodej,
c    1         'rho(1)=',rho(1),
c    1         'rho(2)=',rho(2)
C
C ... CONSTRUCT THE MODAL AUTOCORRELATION
C
        DO 120 MODEN = 1, NSUPER
         DO 110 MODEM = 1, NSUPER
          GFF(MODEN,MODEM,1) = GFF(MODEN,MODEM,1)
     1        + TNM(NODEI,MODEN) * RHO( 1 ) * TNM(NODEJ,MODEM)
          GFF(MODEN,MODEM,2) = GFF(MODEN,MODEM,2)
     1        + TNM(NODEI,MODEN) * RHO( 2 ) * TNM(NODEJ,MODEM)
110       CONTINUE
120      CONTINUE
C
200    CONTINUE
400   CONTINUE
c     write (iw,*) 'Matrix gff(i,j) for omega = ',omega
c     do 1010 moden=1,nsuper
c       write (iw,501) ((gff(moden,modem,k),k=1,2),modem=1,nsuper)
c1010  continue
c501   format(1x,4(1p2e14.7,2x))
C
C ***************************************************************************
C
      RETURN
      END
```

```
C ... SUBROUTINE SETGQQ ... SPECTRAL DENSITY FOR THE MODAL
RESPONSE
C
   SUBROUTINE SETGQQ
   1  (GQQ  ,GFF  ,HFN  ,HFC  ,NSUPER)
C
C *******************************************************************
C **                                       **
C **  COMPUTES THE SPECTRAL DENSITY FOR THE MODAL RESPONSE
**
C **                                       **
C *******************************************************************
C
C  PARAMETERS:
C
C   GQQ    SPECTRAL DENSITY OF THE MODAL RESPONSE
C   GFF    SPECTRAL DENSITY OF THE MODAL FORCING FUNCTION
C   HFN    MODAL TRANSFER FUNCTION AT EXCITATION FREQUENCY
C   HFC    CONJUGATE OF MODAL TRANSFER FUNCTION ABOVE
C   NSUPER  NUMBER OF EIGENVECTORS FOR MODE SUPERPOSITION
C
C  NOTES:
C
C  * THIS SUBROUTINE IS CALLED BY:
C
C   FREDOM   TO COMPUTE THE ONE-SIDED SPECTRAL DENSITY
FUNCTION FOR
C          THE MODAL RESPONSE DUE TO P.S.D. EXCITATION
C
C        *
C  * FIRST, H (w) IS COMPUTED FROM FROM H (w) FOR ALL MODES
C         n                 n
C
C  * THEN, THE VALUES OF
C
C   _          *  _
C   G    (w) = H (w) H (w) G    (w)
C    qn qm      n    m    fn fm
C
C   ARE COMPUTED, WHERE
C
C           _
C   G    (w) = G    (w) psd(w)
C    qn qm      qn qm
C
```

```
C   * THE MULTIPLICATIVE FACTOR psd(w) IS INCLUDED IN THE WEIGHT
FACTOR
C    USED IN THE NUMERICAL INTEGRATION OVER THE FREQUENCY BAND
C
C ********************************************************************
C
c    IMPLICIT REAL*8 ( A-H , O-Z )
      implicit none
      real*8   areal,aimag,
     1        gqq,gff,hfn,hfc
      integer  i,j,nsuper
c    1        ,k,iw
C
      DIMENSION GQQ ( NSUPER , NSUPER , 2 ), HFN ( NSUPER , 2 )
      DIMENSION GFF ( NSUPER , NSUPER , 2 )
c            , HFC ( NSUPER , 2 )
C
C ********************************************************************
C
c     iw = 169
c     write (iw,*) 'hfn(nsuper,2)'
c     do 1 i=1,nsuper
c1     write (iw,501) hfn(i,1),hfn(i,2)
      DO 600 I = 1, NSUPER
       DO 500 J = 1, NSUPER
         areal = hfn(i,1)*hfn(j,1) + hfn(i,2)*hfn(j,2)
         aimag =-hfn(i,1)*hfn(j,2) + hfn(i,2)*hfn(j,1)
         gqq(i,j,1) = gff(i,j,1)*areal - gff(i,j,2)*aimag
500     CONTINUE
600   CONTINUE
c     write (iw,*) '==Matrix gqq(i,j)=='
c     do 1010 i=1,nsuper
c       write (iw,501) ((gqq(i,j,k),k=1,2),j=1,nsuper)
c1010  continue
c501   format(1x,4(1p2e14.7,2x))
C
C ********************************************************************
C
      RETURN
      END
C ... SUBROUTINE SETHFN ... COMPUTES THE MODAL TRANSFER FUNCTION
C
      SUBROUTINE SETHFN
     1  (HFN   ,BETAN ,GMASS ,OMEGN ,OMEGA ,RDAMP ,NSUPER,JDAMP )
C
C ********************************************************************
```

```
C **                                            **
C **  COMPUTES THE MODAL TRANSFER FUNCTION AT A GIVEN
FREQUENCY      **
C **                                            **
C ***********************************************************************
C
C  PARAMETERS:
C
C    HFN     MODAL TRANSFER FUNCTION AT OMEGA
C    BETAN   MODAL DAMPING RATIOS
C    GMASS   GENERALIZED MASS IN EACH MODE
C    OMEGN   SYSTEM NATURAL FREQUENCIES
C    OMEGA   FREQUENCY OF EXCITATION
C    RDAMP   RAYLEIGH DAMPING PARAMETERS
C    NSUPER  NUMBER OF MODES USED FOR SUPERPOSITION
C    JDAMP   DAMPING TYPE FLAG
C          = 1  RAYLEIGH DAMPING
C          = 2  VISCOUS MODAL DAMPING
C          = 3  STRUCTURAL DAMPING
C
C  NOTES:
C
C  * THIS SUBROUTINE IS CALLED BY:
C
C    FREDOM   TO COMPUTE THE MODAL TRANSFER FUNCTIONS USED FOR
LINEAR
C          DYNAMICS ANALYSIS IN THE FREQUENCY DOMAIN
C
C ***********************************************************************
C
      IMPLICIT REAL*8 ( A-H , O-Z )
C
      DIMENSION HFN  ( NSUPER , 2 ), RDAMP(   2   )
      DIMENSION OMEGN( NSUPER )    , BETAN( NSUPER ), GMASS( NSUPER )
C
C ***********************************************************************
C
      DO 700 NN = 1, NSUPER
C
      GO TO ( 100, 200, 300 ), JDAMP
C
C ... TYPE 1:  RAYLEIGH DAMPING
C
  100 CONTINUE
      AREAL = OMEGN(NN)*OMEGN(NN)-OMEGA*OMEGA
      AIMAG = (RDAMP(1)+RDAMP(2)*OMEGN(NN)*OMEGN(NN))*OMEGA
```

```
      GO TO 500
C
C ... TYPE 2:  MODAL VISCOUS DAMPING
C
  200 CONTINUE
      AREAL = OMEGN(NN)*OMEGN(NN)-OMEGA*OMEGA
      AIMAG = 2.00D0*BETAN(NN)*OMEGN(NN)*OMEGA
      GO TO 500
C
C ... TYPE 3:  MODAL STRUCTURAL DAMPING
C
  300 CONTINUE
      AREAL = OMEGN(NN)*OMEGN(NN)-OMEGA*OMEGA
      AIMAG = BETAN(NN)*OMEGN(NN)*OMEGN(NN)
      GO TO 500
C
C ... COMPUTE THE H-FUNCTION
C
  500 CONTINUE
c     GMASSN = 1.00D0/GMASS(NN)
c     CALL CPXDIV(HFN(NN,1),HFN(NN,2),GMASSN,0.00D0,AREAL,AIMAG)
      gmassn = (areal*areal + aimag*aimag)*gmass(nn)
      hfn(nn,1) = areal/gmassn
      hfn(nn,2) =-aimag/gmassn
C
  700 CONTINUE
C
C ********************************************************************
C
      RETURN
      END
C ... SUBROUTINE TIMER ... INDEPENDENT VERSION
C
      SUBROUTINE TIMER(CPUTIM)
C
C ********************************************************************
C **                                                                **
C **  OBTAINS CPU TIMES FOR THE CURRENT RUN                         **
C **                                                                **
C ********************************************************************
C
C  ARGUMENTS:
C
C   CPUTIM   THE C.P.U. CLOCK TIME FOR THIS PROCESS
C
C  NOTES:
```

```
C
C  * THIS SUBROUTINE IS CALLED BY:
C
C   TIMOUT   TO OBTAIN EXECUTION TIMING FOR NESSUS/FEM
C   PRETIM   TO OBTAIN EXECUTION TIMING FOR NESSUS/PRE
C   L1TIM    TO OBTAIN EXECUTION TIMING FOR NESSUS/LEVEL1
C
C ********************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CPUTIM = SECOND( )
      RETURN
      END
C
C SUBROUTINE DATER...................CRAY/UNICOS VERSION
C
      SUBROUTINE DATER( IDAT, IDAT4 )
C
C ********************************************************************
C **                                                                **
C **  GET THE DATE AND TIME OF THE RUN USING SYSTEM CALLS           **
C **                                                                **
C ********************************************************************
C
C   ARGUMENTS:
C
C     IDAT    DAY, MONTH AND YEAR
C     IDAT4   TIME OF THE DAY
C
C   NOTES:
C
C   * THIS SUBROUTINE IS CALLED BY:
C
C     HEADER   TO GET THE SYSTEM DATE AND TIME, WHICH ARE PRINTED
C              ON THE FIRST PAGE OF EVERY OUTPUT FILE.
C
C ********************************************************************
C
      DIMENSION IDAT( 3 ),IDAT4( 3 )
      CHARACTER*8 CDATE,CTIME

      CALL DATE(CDATE)
      CALL CLOCK(CTIME)
      READ(CDATE(1:2),'(I2)') IDAT(1)
      READ(CDATE(4:5),'(I2)') IDAT(2)
      READ(CDATE(7:8),'(I2)') IDAT(3)
```

```
    READ(CTIME(1:2),'(I2)') IDAT4(1)
    READ(CTIME(4:5),'(I2)') IDAT4(2)
    READ(CTIME(7:8),'(I2)') IDAT4(3)
C
    RETURN
    END
    PROGRAM NESSUS
C ... PROGRAM NESSUS ... VERSION 6.1  (JUL. 30TH 1993)
C
C ****************************************************************
C **                                   **
C ****************************************************************
C
C   NN    NN EEEEEEEE  SSSSSSS  SSSSSSS UU   UU  SSSSSSS
C   NNN   NN EE      SS      SS      UU   UU SS
C   NN N  NN EE      SS      SS      UU   UU SS
C   NN N NN EEEEEE   SSSSSS  SSSSSS  UU   UU  SSSSSS
C   NN  N NN EE          SS      SS UU   UU      SS
C   NN   NNN EE          SS      SS UU   UU      SS
C   NN    NN EEEEEEEE SSSSSSS  SSSSSSS   UUUUUU  SSSSSSS
C
C ****************************************************************
C **                                   **
C **  *NESSUS* IS A SOFTWARE SYSTEM FOR THE PROBABILISTIC
ANALYSIS   **
C **  OF REUSABLE SPACE PROPULSION SYSTEM COMPONENTS
DEVELOPED FOR   **
C **  THE NASA LEWIS RESEARCH CENTER UNDER CONTRACT NAS3-24389.
**
C **                                   **
C ****************************************************************
C **                                   **
C **  THE PRESENT VERSION OF THE PROGRAM INCLUDES THE FOLOWING
SIX   **
C **  PROBABILISTIC ANALYSIS MODULES:                    **
C **                                   **
C **    MODULE NAME   DESCRIPTION                    **
C **    -----------   -----------               **
C **  1  NESSUS/PRE    RANDOM FIELD DATA PRE-PROCESSOR          **
C **  2  NESSUS/FEM    FINITE ELEMENT PERTURBATION ANALYSIS DRIVER
**
C **  3  NESSUS/FPI    FAST PROBABILITY INTEGRATION           **
C **  4  NESSUS/LEVEL1  LEVEL 1 PERTURBATION ANALYSIS POST-
PROCESSOR  **
C **  5  NESSUS/PFEM   PROBABILISTIC FINITE ELEMENT DRIVER        **
C **  6  NESSUS/RISK   RISK COMPUTATION                  **
```

```
C ** 7 NESSUS/SRA    SYSTEM RISK ASSESSMENT                        **
C ** 8 NESSUS/SIMFEM SIMulation Finite Element Module              **
C ** 9 NESSUS/BEM    BOUNDARY ELEMENT PERTURBATION ANALYSIS
DRIVER **
C ** 10 NESSUS/SYS   SYSTEM ANALYSIS DRIVER                        **
C ** 11 NESSUS/SYS   SYSTEM RISK ASSESSMENT (VU VERSION)           **
C **                                                               **
C **                                                               **
C *****************************************************************
C **                                                               **
C ** NESSUS/PRE AND FEM WERE DEVELOPED AND CODED BY:               **
C **                                                               **
C **    J. B. DIAS        (MARC/Stanford U.)                       **
C **    J. C. NAGTEGAAL   (MARC)                                   **
C **    S. NAKAZAWA       (MARC)                                   **
C **                                                               **
C *****************************************************************
C **                                                               **
C ** NESSUS/FPI WAS DEVELOPED AND CODED BY:                        **
C **                                                               **
C **    Y.-T. WU          (SwRI)                                   **
C **    T. TORNG          (SwRI)                                   **
C **                                                               **
C *****************************************************************
C **                                                               **
C ** NESSUS/LEVEL1 WAS DEVELOPED BY:                               **
C **                                                               **
C **    O. H. BURNSIDE    (SwRI)                                   **
C **    J. F. UNRUH       (SwRI)                                   **
C **                                                               **
C ** AND CODED BY:                                                 **
C **                                                               **
C **    J. B. DIAS        (MARC/Stanford U.)                       **
C **                                                               **
C *****************************************************************
C **                                                               **
C ** NESSUS/PFEM WAS DEVELOPED AND CODED BY:                       **
C **                                                               **
C **    H. R. MILLWATER   (SwRI)                                   **
C **    B. H. THACKER     (SwRI)                                   **
C **                                                               **
C *****************************************************************
C **                                                               **
C ** NESSUS/RISK WAS DEVELOPED AND CODED BY:                       **
C **                                                               **
C **    H. R. MILLWATER   (SwRI)                                   **
```

```
C **    T. A. CRUSE      (SwRI/VU)                    **
C **                                 **
C *******************************************************************
C **                                 **
C **  NESSUS/SRA  WAS DEVELOPED AND CODED BY:                    **
C **                                 **
C **    H. R. MILLWATER   (SwRI)                   **
C **    J.    WU        (SwRI)               **
C **    T.  TORNG       (SwRI)                **
C **                                 **
C *******************************************************************
C **                                 **
C **  NESSUS/SIMFEM  WAS DEVELOPED AND CODED BY:                 **
C **                                 **
C **    M. SAGAR         (SwRI)               **
C **    H. R. MILLWATER   (SwRI)                   **
C **    J. WU        (SwRI)               **
C **                                 **
C *******************************************************************
C **                                 **
C **  FOR DISTRIBUTION INFORMATION CONTACT:                   **
C **                                 **
C **    D. A. HOPKINS     (NASA-LeRC)                   **
C **                                 **
C **    NASA LEWIS RESEARCH CENTER                    **
C **    21000 BROOKPARK ROAD                    **
C **    MAIL STOP 49-8                    **
C **    CLEVELAND,  OHIO  44135                   **
C **                                 **
C *******************************************************************
C
   IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4  IWORK
C
C *******************************************************************
C **  COMMON BLOCKS                          **
C *******************************************************************
C
   COMMON /       / IWORK  ( 6 400 000 )
   COMMON / MACHIN / IDP
   COMMON / ALGEM  / ICREAD,ILPRNT,JLPRNT,ICONSL,IPOSTF,ISCRAF,
  1            IPLOTB,IRSTRT,JCREAD,IRVBIN,IDBASE,IRVDEF,
  2            PI    ,LINE  ,LINE2
   COMMON / ERRORS / IERR
   COMMON / FREE   / IA    (   80),IBEGIN(   16),ILENGT(   16),
  1            NSTRIN,IS    ,ICOL  ,NEW
```

```
      LOGICAL                    NEW
      COMMON / EXEC   / IEXEC ,IFINAL
C
C Common IVERIN holds the 3 digit integer icremental version number
C read in in subroutine VERSON.
C 25 MAY 1990...B.H.Thacker
C
      COMMON / IVERIN / IVERIN
      COMMON / VERSNO / VERSNO
C
C   common soltyp flags which type of analysis
C ** 1  NESSUS/PRE    RANDOM FIELD DATA PRE-PROCESSOR
C ** 2  NESSUS/FEM    FINITE ELEMENT PERTURBATION ANALYSIS DRIVER
C ** 3  NESSUS/FPI    FAST PROBABILITY INTEGRATION
C ** 4  NESSUS/LEVEL1  LEVEL 1 PERTURBATION ANALYSIS POST-
PROCESSOR
C ** 5  NESSUS/PFEM   PROBABILISTIC FINITE ELEMENT DRIVER
C ** 6  NESSUS/RISK   STAND-ALONE RISK DRIVER
C ** 7  NESSUS/SRA    SYSTEM RELIABILITY DRIVER
C ** 8  NESSUS/SIMFEM  LATIN HYPERCUBE SIMULATION OF PFEM
C ** 9  NESSUS/BEM    BOUNDARY ELEMENT PERTURBATION ANALYSIS
DRIVER
C ** 10  NESSUS/SYS    SYSTEM ANALYSIS DRIVER
C ** 11  NESSUS/SYS    SYSTEM RISK ASSESSMENT (VU VERSION)
C
      COMMON / SOLTYP / ISOL

C *******************************************************************
C **  ANALYSIS OPTIONS                              **
C *******************************************************************
C
      DIMENSION NAME( 4 , 11 )
C
      DATA NEXEC  /   11 /, IBLANK / 1H  /, ISTAR  / 1H* /
C
      DATA NAME   / 1HP,1HR,1HE,1H , 1HF,1HE,1HM,1H , 1HF,1HP,1HI,1H  ,
     1           1HL,1HE,1HV,1HE, 1HP,1HF,1HE,1HM, 1HR,1HI,1HS,1HK ,
     1           1HS,1HR,1HA,1H , 1HS,1HI,1HM,1HF, 1HB,1HE,1HM,1H  ,
     1           1HS,1HY,1HS,1HT, 1HS,1HR,1HI,1HS/
C
C *******************************************************************
C **  VARIABLE INITIALIZATION FOR SIZING AND VERSION NUMBER
**
C *******************************************************************
C
      DATA          ISIZE / 6 400 000 /
```

```
   COMMON / ISIZE / ISIZE
C
   DATA          MONTH / 'July' /, JDATE / '30' /
C
   VERSNO = 6.1D0
C
   MSIZE  = 16 554
   BSIZE  = 16 554
C
C ********************************************************************
C **  THE PARAMETER 'IFCRAY' IS USED FOR SETTING PAGE BANNER
FORMAT  **
C ********************************************************************
C
C   IFCRAY = 0  SUPPORTS SYSTEM CLOCK AND CALENDAR ROUTINES ON
C          PRIME AND VAX/VMS INSTALLATIONS
C
C   IFCRAY = 1  SUPPORTS THE CRAY/COS SYSTEM CLOCK ROUTINES
C
C             IFCRAY=    0
            IFCRAY=    1                    CRAY
C
C ********************************************************************
C **  THE PARAMETER 'IDP' IS USED TO CONTROL MEMORY ALLOCATION
**
C ********************************************************************
C
C   ON TYPICAL 32-BIT MACHINES THIS PARAMETER IS SET TO TWO, SINCE
C   THE DOUBLE PRECISION REALS OCCUPY TWO 32-BIT INTEGER WORDS
C
C   ON 64-BIT SUPERCOMPUTERS, THIS VALUE IS SET TO ONE, SINCE BOTH
C   INTEGERS AND REALS OCCUPY A SINGLE 64-BIT WORD
C
C             IDP  =    2
            IDP  =    1                     CRAY
C
C ********************************************************************
C **  SYSTEM INITIALIZATION ROUTINE 'INTINT'                **
C ********************************************************************
C
C   PRIME  OPEN FILES USING PRIMOS SYSTEM CALLS
C   IBM   SUPRESS ERROR MESSAGES (H-COMPILER ONLY)
C   CRAY  DUMMY SUBROUTINE CALL
C   VAX   OPEN FILES USING FORTRAN 77 EXTENSIONS
C
   CALL VERINC
```

```
      CALL PROMPT
      CALL INTINT
      CALL REINIT
C
C ************************************************************************
C ** PARSE THE FIRST LINE FOR AN APPROPRIATE EXECUTION FLAG
**
C ************************************************************************
C
C ... CHECK THE FIRST LINE FOR AN EXECUTION FLAG
C
      IEXEC = 2
      READ(ICREAD,1200,END=600) IA
      DO 200 K = 1, 80
       IF (IA(K).EQ.ISTAR) GO TO 220
  200 CONTINUE
      REWIND(ICREAD)
      GO TO 300
C
C ... CHECK THE EXECUTION FLAG AGAINST THE OPTIONS
C
  220 CONTINUE
      DO 260 J = 1, NEXEC
       DO 250 I = 1, 4
        IF (IA(K+I).NE.NAME(I,J)) GO TO 260
  250  CONTINUE
       IEXEC = J
       GO TO 300
  260 CONTINUE
      REWIND(ICREAD)
  300 CONTINUE
C
C ... BRANCH TO THE APPROPRIATE ANALYSIS MODULE
C
C ************************************************************************
C
C    *********************************************************************
C    ** RANDOM FIELD DATA PRE-PROCESSOR                                 **
C    *********************************************************************
C
      IF    (IEXEC .EQ. 1) THEN
C
      ISOL = 1
      CALL PRE   ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE )
C
C    *********************************************************************
```

```
C    ** FINITE ELEMENT PERTURBATION ANALYSIS DRIVER          **
C    ***************************************************************
C
     ELSE IF (IEXEC .EQ. 2) THEN
C
       ISOL = 2
       CALL FEM   ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE )
C
C    ***************************************************************
C    ** FAST PROBABILITY INTEGRATION CODE                    **
C    ***************************************************************
C
     ELSE IF (IEXEC .EQ. 3) THEN
C
       REWIND(ICREAD)
C
       ISOL = 3
       CALL FPI( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
C    ***************************************************************
C    ** LEVEL 1 PERTURBATION ANALYSIS POST-PROCESSOR         **
C    ***************************************************************
C
     ELSE IF (IEXEC .EQ. 4) THEN
C
       ISOL = 4
       CALL LEVEL1( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE )
C
C    ***************************************************************
C    ** PROBABILISTIC FINITE ELEMENT DRIVER                  **
C    ***************************************************************
C
     ELSE IF (IEXEC .EQ. 5) THEN
C
       ISOL = 5
       CALL PFEM  ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
C    ***************************************************************
C    ** RISK                          **
C    ***************************************************************
C
     ELSE IF (IEXEC .EQ. 6) THEN
C
       ISOL = 6
       JERROR = 0
       CALL RISK  ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE,
```

```
     $           ICREAD, JERROR )
C
C    **************************************************************
C    ** SRA                                **
C    **************************************************************
C
     ELSE IF (IEXEC .EQ. 7) THEN
C
      ISOL = 7
      CALL SRA   ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
C    **************************************************************
C    ** SIMFEM                               **
C    **************************************************************
C
     ELSE IF (IEXEC .EQ. 8) THEN
C
      ISOL = 8
      CALL SIMFEM ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
C    **************************************************************
C    ** BEM                                **
C    **************************************************************
     ELSE IF (IEXEC .EQ. 9) THEN
C
      ISOL = 9
      CALL BEM   ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
C
C    **************************************************************
C    ** SYSTEM                               **
C    **************************************************************
     ELSE IF (IEXEC .EQ. 10) THEN
C
      ISOL = 10
      CALL SYS   ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
C
C    **************************************************************
C    ** SYSRSK                               **
C    **************************************************************
     ELSE IF (IEXEC .EQ. 11) THEN
C
      ISOL = 11
      CALL SYS   ( IWORK, IWORK, ISIZE, VERSNO, MONTH, JDATE)
C
```

```
      ENDIF
C
C
C *****************************************************************
C
C ... EXIT WHEN THE EXECUTION IS SUCCESSFULLY TERMINATED
C
      STOP
C
C ... EXIT IF THE INPUT FILE IS EMPTY
C
  600 CONTINUE
      WRITE(ICONSL,1300)
      WRITE(ILPRNT,1300)
      CALL QUIT('INPU','T    ','    ','    ','    ','    ',1)
      STOP
C
C ********************************************************************
C **  FORMAT STATEMENTS                                         **
C ********************************************************************
C
 1200 FORMAT(80A1)
 1300 FORMAT(//,1X,'*** ERROR ***     INPUT FILE IS EMPTY',//)
C
      END
C ... SUBROUTINE TIMER ... INDEPENDENT VERSION
C
      SUBROUTINE TIMER(CPUTIM)
C
C ********************************************************************
C **                                                              **
C **  OBTAINS CPU TIMES FOR THE CURRENT RUN                       **
C **                                                              **
C ********************************************************************
C
C  ARGUMENTS:
C
C   CPUTIM   THE C.P.U. CLOCK TIME FOR THIS PROCESS
C
C  NOTES:
C
C  * THIS SUBROUTINE IS CALLED BY:
C
C   TIMOUT   TO OBTAIN EXECUTION TIMING FOR NESSUS/FEM
C   PRETIM   TO OBTAIN EXECUTION TIMING FOR NESSUS/PRE
C   L1TIM    TO OBTAIN EXECUTION TIMING FOR NESSUS/LEVEL1
```

```
C
C *********************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CPUTIM = 0.0
      RETURN
      END
      SUBROUTINE UOPERA(
     1  ILPRNT, ICONSL, IFMVR,  IOPT,  NCOEF, RCOEF, NSRANV, VALIV,
     2  NICM,   NNOD,   NIMS,   XTRVAL,FEMRES,JERR  )
C
C *********************************************************************
C **      USER SUBROUTINE TO DEFINE F.E.M. RESPONSE VARIABLES        **
C *********************************************************************
C
C
C  ARGUMENTS (S-SENT, R-RETURNED):
C
C    ILPRNT - S - OUTPUT FILE UNIT NUMBER
C    ICONSL - S - SCREEN UNIT NUMBER
C     IFMVR - S - F.E.M. RESPONSE VARIABLE NUMBER
C      IOPT - S - OPTION NUMBER FOR F.E.M. RESPONSE VARIABLE IFMVR
C     NCOEF - S - NUMBER OF USER-DEFINED COEFFICIENTS FOR OPTION
IOPT
C     RCOEF - S - VALUES OF THE USER-DEFINED COEFFICIENTS
C    NSRANV - S - NUMBER OF RANDOM VARIABLES WHICH WERE INPUT
TO F.E.M.
C             AND EXTRACTED FROM THE PERTURBATION DATABASE
C     VALIV - S - CORRESPONDING VALUES OF THESE RANDOM VARIABLES
C      NICM - S - NUMBER OF COMPONENTS EXTRACTED FROM THE
PERTURBATION
C             DATABASE TO DEFINE F.E.M. RESPONSE VARIABLE NUMBER
C             IFMVR
C      NNOD - S - NUMBER OF NODES EXTRACTED FROM THE
PERTURBATION
C             DATABASE TO DEFINE F.E.M. RESPONSE VARIABLE NUMBER
C             IFMVR
C      NIMS - S - NUMBER OF INCREMENTS, MODES, OR SPECTRAL CASES
C             (DEPENDING ON THE ANALYSIS TYPE) EXTRACTED FROM
C             THE PERTURBATION DATABASE TO DEFINE F.E.M. RESPONSE
C             VARIABLE NUMBER IFMVR
C    XTRVAL - S - THE F.E.M.-COMPUTED VALUES EXTRACTED FROM THE
C             PERTURBATION DATABASE TO DEFINE F.E.M. RESPONSE
C             VARIABLE NUMBER IFMVR
C    FEMRES - R - THE VALUE OF F.E.M. RESPONSE VARIABLE NUMBER
IFMVR
```

```
C     IERR - R - ERROR CODE
C               0 = NORMAL TERMINATION
C               1 = ERRORS DETECTED
C
C *********************************************************************
C  EXAMPLE USAGE:
C  IF ONLY ONE F.E.M.-COMPUTED QUANTITY WAS EXTRACTED FROM THE
C  PERTURBATION DATABASE TO DEFINE F.E.M. RESPONSE VARIABLE
NUMBER
C  IFMVR, CODE TO RETURN THIS VALUE WOULD BE:
C
C           FEMRES = XTRVAL(1,1,1)
C
C *********************************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      REAL*4 RCOEF(NCOEF)
      common /uinit_geo/ init
      DIMENSION VALIV(NSRANV)
      DIMENSION XTRVAL(NICM,NNOD,NIMS)
C
C.....................................................................
C
      JERR = 0
C
      GOTO ( 1000 ), IOPT
C
C INVALID OPERATION
C
      WRITE(ICONSL,900) IOPT
      WRITE(ILPRNT,900) IOPT
  900 FORMAT(/,' [UOPERA] - OPTION NUMBER ',I2,' IS INVALID.')
C
C *********************************************************************
C * USER OPERATION 1                                                  *
C *********************************************************************
C
 1000 CONTINUE
c
C     the following code modified by RAJ 06/09/95
C     reflects the deck for redeign analysis of the tvane
C     ss1=xtrval(1,1,1)
C     ss2=xtrval(1,1,2)
C     rms=sqrt(2.0d0*ss1+2.0d0*ss2)
      ss1=xtrval(1,1,1)
      ss2=xtrval(1,1,2)
```

```
      ss3=xtrval(1,2,1)
      ss4=xtrval(1,2,2)
      rms=sqrt(ss1+ss2+ss3+ss4)
      FEMRES=rms
 c
      write(*,*)
      write(*,*) 'from uopera:'
      write(*,*) 'IFMVR:',IFMVR
      write(*,*) 'IOPT:',IOPT
      write(*,*) 'NCOEF:',NCOEF
      write(*,*) 'RCOEF:',RCOEF
      write(*,*) 'NSRANV:',NSRANV
      write(*,*) 'VALIV:',VALIV
      write(*,*) 'NICM:',NICM
      write(*,*) 'NNOD:',NNOD
      write(*,*) 'NIMS:',NIMS
      write(*,*) 'XTRVAL:',XTRVAL
      write(*,*) 'FEMRES:',FEMRES
      init=0
      GOTO 9999
C
C ALL DONE
C
 9999 RETURN
      END
c**********************************************************************
c
c             U P S R H O
c             ==============
c
c     User Defined Cross Correlation Model
c
=======================================================================
c
c
c  This Module Includes the Following Subroutines
c
c     UPSRHO   - Main control to obtain the matrix of cross correlation
c     CCC_ONCE - Opening files & invoked only the 1st time UPSRHO is called
c     CCC_LOGO - Prints a logo to locate UPSRHO version
c     CCC_INI  - Initialization Routine invoked only once / perturbation
c     CCC_INID - Initialization for distance dep. models
c     CCC_INIF - Initialization for Frequency dep. models
c     CCC_SDD  - Simple Distance dependent correlation model
c     CCC_DIST - Compute distance (along & across) between points
c     CCC_FDD  - Frequency & Distance dependent (Travelling wave) model
```

```
c
c
c
c Last Modified On 05-26-94
c Last Modified On 07-10-94
c Last Modified On 11-14-94  modified CCC_DIST to account for 0 dist
c
c*********************************************************************
   subroutine UPSRHO
  1  (rho,nodei,nodej,coor,nnode,maxcrd,omega,jpsd)
c=====================================================================
c
c  DEFINES A CORRELATION FUNCTION BETWEEN THE P.S.D. LOADING AT
c  NODE I AND NODE J IN TERMS OF THE EXCITATION FREQUENCY OMEGA
c
c
c Called By SETGFF   - Main control to set cross correlation
c
c Calls    CCC_ONCE  - Opening I/O files & one time initialization routine
c          CCC_INI   - Initialization for each perturbation
c          CCC_SDD   - Linear Distance Dependent Model
c          CCC_FDD   - Frequency & Distance Dependent Model
c
c
c Written  By Diez (South West Research)   On 05-02-92
c  *as a dummy code
c
c Modified By Amitabha DebChaudhury       On 07-01-94
c  *Structured to add a variety of correlation models
c  *Added distance dependent correlation model
c  *Added Frequency & distance dependent correlation model
c Modified By GEO                         On 02-06-95
c  *Added upscoef to pass correlation parameters from
c   PFEM deck through ZFUNCT coefficients
c  *Included CLS driver
c
c---------------------------------------------------------------------
c
c Input
c   Name    Type    Description
c   ------  ------  ------------------
c   NODEI   Integer THE FIRST NODE IN A PAIR
c   NODEJ   Integer THE SECOND NODE IN A PAIR
c   COOR    Real*8  NODAL COORDINATE ARRAY
c   NNODE   Integer NUMBER OF NODES IN THE MODEL
c   MAXCRD  Integer MAXIMUM NUMBER OF COORDINATES PER NODE
```

```
c    OMEGA    Real*8   THE FREQUENCY OF EXCITATION
c    JPSD     Integer  THE P.S.D. EXCITATION NUMBER
c
c Output
c    Name     Type     Description
c    ------   ------   -------------------
c    RHO(1)   Real*8   CORRELATION COEFFICIENT  (REAL PART)
c    RHO(2)   Real*8   CORRELATION COEFFICIENT  (IMAGINARY)
c
c NOTES
c
c * THIS SUBROUTINE IS CALLED BY
c
c    SETGFF   TO CONSTRUCT THE ONE-SIDED SPECTRAL DENSITY
FUNCTION
c             FOR THE FORCING TERM OF THE P.S.D. EXCITATION
c
c  * THE ONE-SIDED SPECTRAL DENSITY FUNCTION FOR THE FORCING
TERM
c    BETWEEN NODES i AND j IS DEFINED AS
c
c     G (w) = fbar fbar rho (w) psd (w)
c      ij         i   j  ij
c
c    WHERE
c
c     fbar    LOCAL INTENSITY OF P . S . D . EXCITATION AT NODE i
OBTAINED
c        i    FROM THE SPATIAL DEFINITION PART OF THE P.S.D. INPUT
c
c     rho  (w) SPATIAL CORRELATION COEFFICIENT BETWEEN NODES i AND j
AS
c        ij   DEFINED IN THIS USER ROUTINE
c
c     psd (w)       VALUE OF THE P . S . D . AS A FUNCTON OF FREQUENCY
OBT.
c               BY LINEAR INTERPOLATION OF THE TABULAR DATA DEFINED IN
c               THE SPECTRAL INTENSITY PART OF THE P.S.D. INPUT
c
c  * THE CORRELATION COEFFICIENT HAS BOTH REAL AND IMAGINARY
PARTS SO
c    THAT NOT ONLY THE INTENSITY OF CORRELATION BUT ALSO THE
PHASE CAN
c    BE SPECIFIED BY THE USER.  A TYPICAL CORRELATION FUNCTION FOR
A
```

```
c   HOMOGENEOUS RANDOM PRESSURE FIELD ARISING FROM BOUNDARY
LAYER
c   TURBULENCE IN THE NEAR FIELD OF A JET EXHAUST COULD BE TAKEN
AS
c
c              c w          C w
c            - --- abs ( dx )  - i -----  dx
c              V            V
c    rho (w ) = e              e
c      ij
c
c   WHERE
c
c     c     IS THE CORRELATION DECAY PARAMETER
c     w     IS THE FREQUENCY OF EXCITATION, OMEGA
c     V     IS THE CONVECTION SPEED
c     dx    IS THE SEPARATION DISTANCE BETWEEN NODES i AND j
c
c THIS MODEL HAS BEEN PROPOSED BY J. UNRUH (SwRI).
c
c * SIMPLER CORRELATION MODELS CAN ALSO BE USED. FOR INSTANCE,
FOR
c  SPATIALLY UNCORRELATED, FREQUENCY INDEPENDENT LOADING, WE
HAVE
c
c   rho  = 1   IF i AND j ARE THE SAME POINT
c    ij
c
c   rho  = O   OTHERWISE
c    ij
c
c THIS MODEL WILL GENERALLY YIELD CONSERVATIVE RESULTS.
c
c
c==============================================================
===============
c==============================================================
===============
      implicit none
c
      integer mpert,mranv
c
      PARAMETER (MPERT=201, MRANV=100)
c
      real*8     rcoef,
     1           vcoef,rho,coor,omega
```

```
      integer     init,icoef,nvcoef,nrcoef,nicoef,ir,iw,ierr,
     1            iunit,jperi,ncoef,jpvaru,
     2            nodei,nodej,nnode,maxcrd,jpsd
      integer
     +  ITYPE,  IVAR,
     +  ICOND1, ICOND2, NODE1,  NODE2,  ICOMP1, ICOMP2, ILAY1,  ILAY2,
     +  NPERT,  NVAR,   NUMPRT, NRNVAR, IRST,
     +  ICND1A, ICND2A, NODE1A, NODE2A, ICMP1A, ICMP2A, ILAY1A,
ILAY2A,
     +  NMOVE,  MOVAR,  IDMOD,  NPCOEF,
     +  MREC,   MRECD1, MRECD2, MRECD3,
     +  IPAAM,  NSPERT, NSRANV, IAMVFG, IPRTNO
      double precision PFCOEF,XPRTPT,UMPP,upscoef
      character*80 ccc_model
c
      dimension rho(2), coor(maxcrd,nnode),rcoef(20),icoef(20)
      integer icount
      data icount / 0 /
c=====
c Labelled Common usrcof
c  iunit        Int     ?
c  jperi        Int     ?
c  ncoef        Int     size of vcoef() ? is it 10 ?
c  vcoef(10)    Real*8  User coefficients vcoef(10)
c          *** alignment of vcof() may cause performance degradation - amit
c          *** not a good practice - change later if possible
c
c Labelled Common usrcof
c  jpvaru       Int     perturbation number
c=====
      common /usrcof/ iunit, jperi, ncoef, vcoef(10)
      common /usrprt/ jpvaru
c
      COMMON /PFEMDT/
     +  ITYPE,  IVAR,
     +  ICOND1, ICOND2, NODE1,  NODE2,  ICOMP1, ICOMP2, ILAY1,  ILAY2,
     +  NPERT(MPERT),   NVAR(MRANV),    NUMPRT, NRNVAR, IRST,
     +  ICND1A, ICND2A, NODE1A, NODE2A, ICMP1A, ICMP2A, ILAY1A,
ILAY2A,
     +  NMOVE,  MOVAR,  IDMOD,  NPCOEF, PFCOEF(200),
     +  MREC,   MRECD1(25),    MRECD2(25),    MRECD3(25),
     +  IPAAM,  NSPERT, NSRANV, IAMVFG
      COMMON /PRTPT/ XPRTPT(MRANV),UMPP(MRANV),IPRTNO
      DIMENSION upscoef(11)
c=====
c Local variables
```

```
c  rcoef(nrcoef) Real*8   Work space for faster execution
c  icoef(nicoef) Integer  Work space for faster execution
c  ccc_model     Char*80  cross correlation model
c  init          Int      Indicator to recognize entry sequence
c  ir            Int      Unit number to read additional input
c  iw            Int      Unit number to write additional output
c  nvcoef        Int      Size of the array vcoef()
c  nrcoef        Int      Size of the array rcoef()
c  nicoef        Int      Size of the array icoef()
c  ierr          Int      Error flag
c=====
      save init,nvcoef,nrcoef,nicoef,ir,iw,rcoef,icoef,ccc_model
      save icount,upscoef
      data init / -99 /
      data ccc_model / 'DAL' /
c=====
c  Initialize , if this is the very first call to UPSRHO , or
c  if it is the first call for a new perturbation
c=====
      ierr = 0
c
      if ( init .ne. jpvaru ) then
c--
c  If it is the first time this routine is called
c--
        if(init.eq.-99) then
          nvcoef = 11
          nrcoef = 20
          nicoef = 20
          ir = 22
          iw = 6
          call CCC_ONCE(upscoef,rcoef,ccc_model,icoef,
     1               nvcoef,nrcoef,nicoef,ir,iw,ierr)
        endif
        init = jpvaru
        write (iw,*) ' Starting Random Vibration Analysis for ',
     1  'Purturbation ',jpvaru
c--
c  If it is the first time of a new perturbation
c--
c=====
c  Call CLS driver to calculate flow-rate
c=====
        call NESCLSICM(vcoef,pfcoef,upscoef)
        call CCC_INI(upscoef,rcoef,ccc_model,icoef,
     1             nvcoef,nrcoef,nicoef,ir,iw,ierr)
```

```
      endif
c=====
c The two nodes nodei & nodej are one & the same
c=====
      if (nodei.eq.nodej) then
       rho(1) = 1.0
       rho(2) = 0.0
      else
c=====
c Compute the cross correlation coefficient between two points nodei & nodej
c=====
       if(ccc_model(1:7).eq.'UN_CORR') then
c--
c Uncorrelated between nodes
c--
        rho(1) = 0.0
        rho(2) = 0.0
       else if(ccc_model(1:4).eq.'CORR') then
c--
c Fully correlated between nodes
c--
        rho(1) = 1.0
        rho(2) = 0.0
       else if(ccc_model(1:1).eq.'D') then
c--
c Partially correlated between nodes - Simple distance dependent
c--
        call CCC_SDD(rho,coor,upscoef,rcoef,ccc_model,
     1       nvcoef,nrcoef,nodei,nodej,nnode,maxcrd,iw,ierr)
c--
c Partially correlated between nodes - Travelling wave type
c--
       else if(ccc_model(1:1).eq.'F') then
        call CCC_FDD(rho,coor,omega,upscoef,rcoef,ccc_model,icoef,
     1       nvcoef,nrcoef,nicoef,nodei,nodej,nnode,maxcrd,iw,ierr)
c--
       endif
      endif
c-----------------------------End of UPSRHO-----------------------------------
      return
      end
      subroutine CCC_ONCE(vcoef,rcoef,ccc_model,icoef,
     1              nvcoef,nrcoef,nicoef,ir,iw,ierr)
c==========================================================================
==============
c
```

```
c  Opens extra read & write units & reads correlation model if the file
c  cross_corr_inp exists
c
c
c  Called By UPSRHO   - Main control to set cross correlation
c
c  Calls    CCC_LOGO  - Prints logo to locate UPSRHO version & info
c
c
c
c  Written  By Amitabha DebChaudhury       On 05-02-94
c
c  Modified By Amit                        On 05-23-94
c
c---------------------------------------------------------------------------
c Given
c  Name           Type   Description
c ---------       -------- ----------------
c  vcoef(nrcoef)     Real*8  Real coefficients related to R.V.
c  rcoef(nrcoef)     Real*8  User defined real coefficients
c  icoef(nicoef)     Integer User defined integer coefficients
c  ccc_model         Char*80 Correlation Model ID  (Default name DAL )
c  nvcoef          Integer Size of vcoef()
c  nrcoef          Integer Size of rcoef()
c  nicoef          Integer Size of icoef()
c  ir            Integer Unit number for input
c  iw             Integer Unit number for output
c
c Returns
c  Name           Type   Description
c ---------       -------- ----------------
c  ccc_model         Integer Correlation Model ID
c  ierr            Integer Error flag (0 - no error)
c
c
c Common  None
c
c Local Variables Defined as needed
c
c=================================================================
===============
      implicit none
      character*80 flname,ccc_model
      real*8      vcoef,rcoef
      logical     maybe
      integer     k,
```

```
     1          icoef,nvcoef,nrcoef,nicoef,ir,iw,ierr
      dimension vcoef(nvcoef),rcoef(nrcoef),icoef(nicoef)
c=====
c Initialize, the very 1st time this code is called
c=====
      ierr = 0
c==
c Open the output file
c==
      flname = 'void'
      inquire( unit = iw ,exist = maybe)
      if( maybe ) then
        write(* ,* ) ' *Warning in CCC_ONCE The Output unit id ',iw,
     1  'is in use & is assigned to filename ',flname,
     2  ' Try a new one '
        ierr = 1
        iw = 6
      else
        flname = 'cros_corr_out'
        open(iw,file=flname,status='UNKNOWN',access='SEQUENTIAL')
        write(iw,*) 'Opened file ',flname, ' as unit ',iw
      endif
c==
c Print logo specifying update information
c==
      call ccc_logo(iw)
c==
c Open the input file
c==
      flname = 'void'
      inquire( unit=ir ,exist = maybe)
c**Fix it later
      maybe = .false.
      if( maybe ) then
c--
c The unit ir is already in use
c--
        write(* ,* ) ' *Error in CCC_ONCE The Input unit id ',ir,
     1  'is in use & is assigned to filename ',flname,
     2  ' Try a new one '
        ierr = 2
        ir = 5
c--
c The unit ir is free
c--
      else
```

```
      flname = 'cros_corr_inp'
      inquire(exist = maybe , file = flname)
c-
c  The file cros_corr_inp exists - Read corr_model name from this data file
c-
      if( maybe ) then
        open(ir,file=flname,status='OLD',access='SEQUENTIAL')
        write(iw,*) ' Opened input file ',flname, ' as unit ',ir
        read  (ir,500) ccc_model
        write (iw,*) ' The cross correlation model is ',ccc_model
c
c  Read additional parameters for frequency dependent models
c
        read  (ir,*)  (icoef(k),k=1,4)
        write (iw,702) (icoef(k),k=1,4),vcoef(10)
        close (ir)
c-
c  Assumes the default correlation model name  DAL
c-
      else
        write (iw,*) ' *Warning in CCC_ONCE Missing file ',
     1   'cros_corr_inp that defines the cross correlation model'
        write (iw,*) '  The default cross correlation model ',
     1   'will be used ccc_model = ',ccc_model
      endif
    endif
c==
c  Terminate execution if an error is detected
c==
    if(ierr.gt.1) stop
c
500   format(a80)
702   format(//5x,'Skl(omega) = Skk(omega) * ',/,31x,
     1'[exp{-lamdar* omega**',i2,'* | distr(k,l)/V |**',i2,'}] *',/31x,
     2'[exp{-lamdac* omega**',i2,'* | distc(k,l)/V |**',i2,'}] *',/31x,
     3'[exp{-i* lamdar* omega* | distr(k,l)/V | }] * ',//,5x,
     4'Where V = ',e12.5,//)
c--------------------------------End of CCC_ONCE----------------------------------
    return
    end
    subroutine CCC_INI(vcoef,rcoef,ccc_model,icoef,
   1           nvcoef,nrcoef,nicoef,ir,iw,ierr)
c===============================================================
==============
c
c  Initializes parameters & prints them, the very first time it is called for
```

```
c  a given perturbation
c
c
c Called By UPSRHO   - Main control to set cross correlation
c
c Calls    CCC_INID  - Initializes the distance dependent model
c          CCC_INIF  - Initializes the frequency dependent model
c
c
c
c Written  By Amitabha DebChaudhury      On 05-02-94
c
c Modified By Amit                        On 05-25-94
c
c--------------------------------------------------------------------------
c Given
c Name            Type    Description
c ---------       -------- ----------------
c vcoef(nvcoef)   Real*8  Parameters defining the cross correlation model
c icoef(nicoef)   Integer User defined integer coefficients
c ccc_model       Char*80 Correlation Model ID
c nvcoef          Integer size of vcoef()
c nrcoef          Integer size of rcoef()
c nicoef          Integer size of icoef()
c ir              Integer Unit number for input
c iw              Integer Unit number for output
c
c Returns
c Name            Type    Description
c ---------       -------- ----------------
c rcoef(nrcoef)   Real*8  Parameters computed here dependent on vcoef()
c ierr            Integer Error flag (0 - no error)
c
c
c Common  None
c
c Local Variables Defined as needed
c
c===========================================================================
===============
      implicit none
      character*80 ccc_model
      real*8     vcoef,rcoef
      integer    icoef,nvcoef,nrcoef,nicoef,ir,iw,ierr
c
      dimension vcoef(nvcoef),rcoef(nrcoef),icoef(nicoef)
```

```
c=====
c  Initialize, the very 1st time this code is called for a perturbation
c  & Print the correlation parameters for available models
c=====
      write (iw,*) 'nvcoef,nrcoef,nicoef ',nvcoef,nrcoef,nicoef
      ierr = 0
c=====
c  Uncorrelated between nodes
c=====
      if(ccc_model(1:7).eq.'UN_CORR') then
        write (iw,*) 'For the cross correlation model ',ccc_model(1:7),
     1 'invoked, the cross correlation parameters remains unchanged'
c=====
c  Fully correlated between nodes
c=====
      else if(ccc_model(1:4).eq.'CORR') then
        write (iw,*) 'For the cross correlation model ',ccc_model(1:4),
     1 'invoked, the cross correlation parameters remains unchanged'
c=====
c  Linear Distance Dependent Model
c=====
      else if(ccc_model(1:1).eq.'D') then
        call CCC_INID(vcoef,rcoef,ccc_model,
     1               nvcoef,nrcoef,ir,iw,ierr)
c=====
c  Frequency &  Distance Dependent Model
c=====
      else if(ccc_model(1:1).eq.'F') then
        call CCC_INIF(vcoef,rcoef,ccc_model,icoef,
     1               nvcoef,nrcoef,nicoef,ir,iw,ierr)
c=====
c  Error Trap Unknown correlation Model
c=====
      else
        write (iw,*) '*Error in CCC_INI Unknown Correlation Model ',
     1  ccc_model(1:4),' - valid models are UNCORR  CORR  D**  &  F**'
        ierr = 2
      endif
      if(ierr.gt.1) stop
c-----------------------------End of CCC_INI---------------------------------
      return
      end
      subroutine CCC_INID(vcoef,rcoef,ccc_model,
     1               nvcoef,nrcoef,ir,iw,ierr)
c=================================================================
==============
```

```
c
c  Initializes parameters for distance dependent models
c
c
c
c  Called By CCC_INI  -  Initializes for each perturbation
c
c  Calls     none
c
c
c
c  Written  By Amitabha DebChaudhury       On 05-02-94
c
c  Modified By Amit                        On 05-19-94
c
c---------------------------------------------------------------------------
c Given
c  Name            Type    Description
c ---------        -------- ----------------
c  vcoef(nvcoef)     Real*8  Parameters defining the cross correlation model
c  ccc_model         Char*80 Correlation Model ID
c  nvcoef            Integer size of vcoef()
c  nrcoef            Integer size of rcoef()
c  ir                Integer Unit number for input
c  iw                Integer Unit number for output
c
c Returns
c  Name            Type    Description
c ---------        -------- ----------------
c  rcoef(nrcoef)     Real*8  Parameters computed here dependent on vcoef()
c  ierr              Integer Error flag (0 - no error)
c
c
c Common  None
c
c Local Variables Defined as needed
c
c==============================================================
===============
      implicit none
      character*80 ccc_model
      real*8      dum,
     1            vcoef,rcoef
      integer     i,
     1            nvcoef,nrcoef,ir,iw,ierr
c
```

```
      dimension vcoef(nvcoef),rcoef(nrcoef)
c=====
c  Print the correlation parameters for available models
c=====
      ierr = 0
      write (iw,701) ccc_model(1:4),(vcoef(i),i=1,6)
c--
c  Check for valid coeffn.
c--
      if(vcoef(1).ge.vcoef(4)) then
        write (iw,*) '*Error in CCC_INID invalid coefficients ',
     1  '(distance1 = vcoef(1) = ',vcoef(1),') must be < ',
     2  '(distance2 = vcoef(4) = ',vcoef(4),')'
        ierr = 2
      endif
      if(abs(vcoef(3)).gt.1.0) then
        write (iw,*) '*Error in CCC_INID invalid coefficient corr1',
     1   '= vcoef(3) = ',vcoef(3),' it must lie between -1 & +1'
        ierr = 2
      endif
      if(abs(vcoef(6)).gt.1.0) then
        write (iw,*) '*Error in CCC_INID invalid coefficient corr2',
     1   '= vcoef(6) = ',vcoef(6),' it must lie between -1 & +1'
        ierr = 2
      endif
c=====
c  Distance measured is the absolute distance between the two points
c=====
      if(ccc_model(2:2).eq.'A') then
        write (iw,*) 'The absolute Distance between the two points',
     1   'will be used'
c=====
c  Distance measured relative to a focal point
c=====
      else if(ccc_model(2:2).eq.'R') then
        write (iw,*) 'The Distance between the two points',
     1    'will be obtained relative to the focal point (',
     2    vcoef(7),', ',vcoef(8),', ',vcoef(9),' )'
c=====
c  Distance measured relative to a given direction (along & across)
c  Make sure it an unit vector
c=====
      else if(ccc_model(2:2).eq.'V') then
        dum = 0.0
        do 1410 i=1,3
          dum = dum + vcoef(i+6)**2
```

```
1410   continue
       dum = sqrt(dum)
       do 1420 i=1,3
        vcoef(i+6) = vcoef(i+6)/dum
1420   continue
       write (iw,*) 'The Distance between the two points',
     1  'will be obtained based on the unit direction vector [ ',
     2  vcoef(7),'i, ',vcoef(8),'j, ',vcoef(9),'k ]'
c=====
c Trap Invalid model
c=====
      else
       write (iw,*) '*Error in CCC_INID Unknown Correlation Model',
     1 ccc_model(1:4),' - valid models are DA*  DR*  &  DV*'
       ierr = 2
      endif
c==
c Compute & Save some constants for Linearly varying model
c The value corr2 at distance dist2 must be > 0
c==
      if(ccc_model(3:3).eq.'L') then
       if(vcoef(1).gt.0.0) then
        rcoef(1) = - ( 1.0 - vcoef(3))/vcoef(1)
       endif
       rcoef(2) = - ( vcoef(3) - vcoef(6))/(vcoef(4) - vcoef(1))
       write (iw,*) 'Linear interpolation will be used'
       write (iw,*) 'rcoef(1)=',rcoef(1),'rcoef(2)=',rcoef(2)
c==
c Compute & Save some constants for exponentially varying model
c The value corr2 at distance dist2 must be > 0
c==
      else if(ccc_model(3:3).eq.'E') then
       if(vcoef(1).gt.0.0) then
        rcoef(1) = - ( log(1.0/vcoef(3)))/vcoef(1)
       endif
       if(vcoef(4).gt.0.0) then
        rcoef(2) = - ( log(vcoef(3)/vcoef(6)))/
     1             (vcoef(4) - vcoef(1))
        write (iw,*) 'Exponential interpolation will be used'
       else
        write (iw,*) '*Error in CCC_INID corr2 = ',vcoef(6),
     1  ' - please supply a value > 0 for the correlation model ',
     2  ccc_model(1:4)
        ierr = 2
       endif
c==
```

```
c  Trap Invalid model
c==
      else
       write (iw,*) ' *Error in CCC_INID Unknown Correlation Model',
     1  ccc_model(1:4),' - valid models are **L  &  **E'
       ierr = 2
      endif
      if(ierr.gt.1) stop
c
701  format(/15x,
     1'C R O S S   C O R R E L A T I O N   P A R A M E T E R S',//35x,
     1'for Correlation model ',a4,//,15x,
     2 e12.5,' - Distance1          ',/,15x,
     2 e12.5,' - Frequency1         ',/,15x,
     3 e12.5,' - Correlation Coeffn1',/,15x,
     4 e12.5,' - Distance2          ',/,15x,
     2 e12.5,' - Frequency2         ',/,15x,
     5 e12.5,' - Correlation Coeffn2',//)
c-----------------------------End of CCC_INID---------------------------------
      return
      end
      subroutine CCC_INIF(vcoef,rcoef,ccc_model,icoef,
     1                    nvcoef,nrcoef,nicoef,ir,iw,ierr)
c=====================================================================
===============
c
c  Initializes parameters for frequency dependent models
c
c
c
c  Called By CCC_INI   -  Initializes for each perturbation
c
c  Calls     none
c
c
c
c  Written  By Amitabha DebChaudhury       On 05-02-94
c
c  Modified By Amit                        On 05-23-94
c
c--------------------------------------------------------------------------
c Given
c  Name            Type   Description
c ---------       -------- ----------------
c  vcoef(nvcoef)    Real*8  Parameters defining the cross correlation model
c  ccc_model        Char*80 Correlation Model ID
```

```
c nvcoef          Integer size of vcoef()
c nrcoef          Integer size of rcoef()
c nicoef          Integer size of icoef()
c ir             Integer Unit number for input
c iw              Integer Unit number for output
c
c Returns
c Name            Type   Description
c ---------       -------- ----------------
c rcoef(nrcoef)     Real*8  Parameters needed for fast execution
c icoef(nicoef)     Integer Parameters needed for fast execution
c ierr             Integer Error flag (0 - no error)
c
c
c Common  None
c
c Local Variables Defined as needed
c
c=================================================================
===============
    implicit none
    character*80 ccc_model
    real*8      dum,c11,c12,c21,c22,c10,c20,
   1           vcoef,rcoef
    integer    i,
   1           icoef,nvcoef,nrcoef,nicoef,ir,iw,ierr
c
    dimension vcoef(nvcoef),rcoef(nrcoef),icoef(nicoef)
c=====
c  Print the correlation parameters for available models
c=====
    ierr = 0
    write (iw,701) ccc_model(1:4),(vcoef(i),i=1,6)
    write (iw,*) 'nvcoef,nrcoef,nicoef ',nvcoef,nrcoef,nicoef
c--
c  Check for valid range of values for the coeffn.
c--
    if(vcoef(1).le.0.0) then
     write (iw,*) '*Error in CCC_INIT invalid coefficient dist1',
   1  '= vcoef(1) = ',vcoef(1),' it must be > 0.0'
     ierr = 2
    endif
    if(vcoef(2).le.0.0) then
     write (iw,*) '*Error in CCC_INIT invalid coefficient freq1',
   1  '= vcoef(2) = ',vcoef(2),' it must be > 0.0'
     ierr = 2
```

```
      endif
      if(vcoef(3).le.0.0 .or. vcoef(3).gt.1.0) then
        write (iw,*) '*Error in CCC_INIT invalid coefficient corr1',
     1  '= vcoef(3) = ',vcoef(3),' it must be > 0.0  & <=  +1.0'
        ierr = 2
      endif
      if(vcoef(4).le.0.0) then
        write (iw,*) '*Error in CCC_INIT invalid coefficient dist2',
     1  '= vcoef(4) = ',vcoef(4),' it must be > 0.0'
        ierr = 2
      endif
      if(vcoef(5).le.0.0) then
        write (iw,*) '*Error in CCC_INIT invalid coefficient freq2',
     1  '= vcoef(5) = ',vcoef(5),' it must be > 0.0'
        ierr = 2
      endif
      if(vcoef(6).le.0.0 .or. vcoef(6).gt.1.0) then
        write (iw,*) '*Error in CCC_INIT invalid coefficient corr2',
     1  '= vcoef(6) = ',vcoef(6),' it must be > 0  & <=  +1'
        ierr = 2
      endif
c=====
c  Distance measured is the absolute distance between the two points
c=====
      if(ccc_model(2:2).eq.'A') then
        write (iw,*) 'The absolute Distance between the two points',
     1  'will be used'
c=====
c  Distance measured relative to a focal point
c=====
      else if(ccc_model(2:2).eq.'R') then
        write (iw,*) 'The Distance between the two points',
     1   'will be obtained relative to the focal point ( ',
     2  vcoef(7),', ',vcoef(8),', ',vcoef(9),' )'
c=====
c  Distance measured relative to a given direction (along & across)
c  Make sure it an unit vector
c=====
      else if(ccc_model(2:2).eq.'V') then
        dum = 0.0
        do 1410 i=1,3
          dum = dum + vcoef(i+6)**2
1410    continue
        dum = sqrt(dum)
        do 1420 i=1,3
          vcoef(i+6) = vcoef(i+6)/dum
```

```
 1420   continue
        write (iw,*) 'The Distance between the two points',
      1  'will be obtained based on the unit direction vector [ ',
      2  vcoef(7),'i, ',vcoef(8),'j, ',vcoef(9),'k ]'
c=====
c  Trap Invalid model
c=====
      else
        write (iw,*) '*Error in CCC_INIF Unknown Correlation Model',
      1 ccc_model(1:4),' - valid models are FA*  FR*  &  FV*'
        ierr = 2
      endif
c==
c  Exponentially decaying correlation in both along & across flow direction
c  but at a different rate
c  Compute & Save some constants
c  * c12 & c21 will be nonzero if we could have more than elements in vcoef()
c==
      if(ccc_model(3:3).eq.'E') then
        c11 = vcoef(1)
        c12 = 0.0
        c21 = 0.0
        c22 = vcoef(4)
c
        if(icoef(2).gt.0) then
          c11 = c11**icoef(2)
          c21 = c21**icoef(2)
        endif
        if(icoef(1).gt.0) then
          c11 = c11*vcoef(2)**icoef(1)
          c21 = c21*vcoef(2)**icoef(1)
        endif
c
        if(icoef(4).gt.0) then
          c12 = c12**icoef(4)
          c22 = c22**icoef(4)
        endif
        if(icoef(3).gt.0) then
          c12 = c12*vcoef(5)**icoef(3)
          c22 = c22*vcoef(5)**icoef(3)
        endif
c
        c10 = log(1.0/vcoef(3))
        c20 = log(1.0/vcoef(6))
        rcoef(2) = 1./(c11*c22 - c12*c21)
        rcoef(1) = (c10*c22 - c20*c12)*rcoef(2)
```

```
      rcoef(2) = (c20*c11 - c10*c21)*rcoef(2)
      write (iw,*) 'rcoef(1)=',rcoef(1),'rcoef(2)=',rcoef(2)
c==
c  Trap Invalid model
c==
     else
      write (iw,*) ' *Error in CCC_INIF Unknown Correlation Model',
    1  ccc_model(1:4),' - valid models are **L  &  **E'
      ierr = 2
     endif
     if(ierr.gt.1) stop
c
701  format(/15x,
    1'C R O S S   C O R R E L A T I O N   P A R A M E T E R S',//35x,
    2'for Correlation model ',a4,//,15x,
    3 e12.5,' - Distance along flow (keeping across flow dist 0)',/15x,
    4 e12.5,' - A Frequency point in Hz',/15x,
    5 e12.5,' - corresponding Correlation Coeffn (0-1)',/15x,
    6 e12.5,' - Distance across flow (keeping along flow dist 0)',/15x,
    7 e12.5,' - Another Frequency point in Hz',/15x,
    8 e12.5,' - corresponding Correlation Coeffn (0-1)',//)
c-----------------------------End of CCC_INIF--------------------------------
     return
     end
     subroutine CCC_SDD(rho,coor,vcoef,rcoef,ccc_model,
    1       nvcoef,nrcoef,nodei,nodej,nnode,maxcrd,iw,ierr)
c=====================================================================
==============
c
c  Defines the cross correlation between nodei & nodej based on a simple
c  linear distance (absolute) dependent model
c
c
c  Called By UPSRHO    - Main control to set cross correlation
c
c  Calls     CCC_DIST  -  Compute the distance between two points
c
c
c
c  Written  By Amitabha DebChaudhury       On 05-02-94
c
c  Modified By Amit                        On 05-20-94
c
c--------------------------------------------------------------------------
c Given
c  Name            Type   Description
```

```
c ---------        -------- ----------------
c  coor(maxcrd,nnode)  Real*8  Nodal co-ordinates
c  vcoef(nvcoef)      Real*8  Parameters defining the cross correlation model
c  rcoef(nrcoef)      Real*8  Parameters computed by ccc_INI
c  ccc_model          Char*80 Correlation Model ID
c  nvcoef            Integer Size of array vcoef()
c  nrcoef            Integer Size of array rcoef()
c  nodei             Integer The node Id of the 1st node
c  nodej             Integer The node Id of the 2nd node
c  nnode             Integer The Maximum Node ID
c  maxcrd            Integer Max no. of attributes in a node
c  iw                Integer Unit number for output
c
c Returns
c  Name              Type   Description
c ---------         -------- ----------------
c  rho(1)            Real*8  Real part of the cross corrln coeffn
c  rho(2)            Real*8  Immaginary part of the cross corrln coeffn
c  ierr              Integer Error flag (0 - no error)
c
c
c Common  None
c
c Local Variables Defined as needed
c
c===========================================================================
===============
      implicit none
      character*80 ccc_model
      real*8      distr,distc,dist1,corr1,dist2,corr2,
     1            rho,coor,vcoef,rcoef
      integer     nvcoef,nrcoef,nodei,nodej,nnode,maxcrd,iw,ierr
c
      dimension coor(maxcrd,nnode),vcoef(nvcoef),rcoef(nrcoef),
     1          rho(2)
c==========
c  Compute the distance between the two points based on various assumption
c==========
      ierr = 0
      call CCC_DIST(distr,distc,coor,vcoef,ccc_model,nvcoef,
     1              nodei,nodej,nnode,maxcrd,iw,ierr)
c--
c  Set parameters for specific PSDF
c--
      dist1 = vcoef(1)
      corr1 = vcoef(3)
```

```
    dist2 = vcoef(4)
    corr2 = vcoef(6)
c==========
c  Compute the cross spectral function for a simple distance dependent model
c==========
    rho(2) = 0.0
c=====
c  linear distance dependent correlation model
c=====
    if(ccc_model(3:3).eq.'L') then
     if(distr.le.dist1) then
      rho(1) = 1.0 + rcoef(1)*distr
     else
      if(distr.ge.dist2) then
       rho(1) = corr2
      else
       rho(1) = corr1 + rcoef(2)*(distr - dist1)
      endif
     endif
c=====
c  Exponentially decaying distance dependent correlation model
c=====
    else if(ccc_model(3:3).eq.'E') then
     if(distr.le.dist1) then
      rho(1) = exp(rcoef(1)*distr)
     else
      rho(1) = corr1*exp(rcoef(2)*(distr - dist1))
     endif
c=====
c  User defined function given in a tabular form stored in rcoef(npnt,2)
c  where npnt = vcoef(10), have to use BNSRCH to obtain corrln
c=====
    else if(ccc_model(3:3).eq.'T') then
     write (iw,*) ' *Error in CCC_SDD Tabular form not ready yet'
     ierr = 2
c=====
c  Unknown correlation model
c=====
    else
     write (iw,*) ' *Error in CCC_SDD unknown correlation model ',
   1          ccc_model(1:3)
     ierr = 2
    endif
    if(ierr.gt.1) stop
c-----------------------------End of CCC_SDD----------------------------------
    return
```

```
      end
      subroutine CCC_DIST(distr,distc,coor,vcoef,ccc_model,nvcoef,
     1              nodei,nodej,nnode,maxcrd,iw,ierr)
c=========================================================================
===============
c
c  Obtain the distance between nodei & nodej based on
c   'A' Absolute distance between nodei & nodej
c   'R' Relative distance between nodei & nodej with respect to a focal point
c   'V' Relative distance between nodei & nodej with respect to a vector
c
c
c  Called By CCC_SDD  - Obtain distance dependent correlation
c           CCC_FDD  - Obtain Frequency & distance dependent correlation
c
c  Calls    none
c
c
c
c  Written  By Amitabha DebChaudhury       On 05-02-94
c
c  Modified By Amit                        On 05-23-94
c
c-------------------------------------------------------------------------
c Given
c  Name            Type    Description
c ---------        -------- ----------------
c  coor(maxcrd,nnode) Real*8  Nodal co-ordinates
c  vcoef(nvcoef)      Real*8  Parameters defining the cross correlation model
c  ccc_model          Char*80 Correlation Model ID
c  nvcoef             Integer Size of array vcoef()
c  nodei              Integer The node Id of the 1st node
c  nodej              Integer The node Id of the 2nd node
c  nnode              Integer The Maximum Node ID
c  maxcrd             Integer Max no. of attributes in a node
c  iw                 Integer Unit number for output
c
c Returns
c  Name            Type    Description
c ---------        -------- ----------------
c  distr              Real*8  Distance between the two points
c  distc              Real*8  Distance across the the flow (propagation) path
c  ierr               Integer Error flag (0 - no error)
c
c
c Common  None
```

```
c
c Local Variables Defined as needed
c
c=============================================================
===============
     implicit none
     character*80 ccc_model
     real*8      dist1,dist2,
    1          distr,distc,coor,vcoef
     integer    k,
    1          nvcoef,nodei,nodej,nnode,maxcrd,iw,ierr
c
     dimension coor(maxcrd,nnode),vcoef(nvcoef)
c=====
c  Compute only the absolute distance between the two points
c=====
     ierr = 0
     if(ccc_model(2:2).eq.'A') then
      distr = 0.0
      do 1210 k=1,3
       distr = distr + (coor(k,nodei) - coor(k,nodej))**2
1210   continue
      if(distr.gt.0.0) distr = sqrt(distr)
      distc =  0.0
c=====
c  Compute the distance between the two points relative to a focal point
c  The focal point is (vcoef(5),vcoef(6),vcoef(7))
c=====
     else if(ccc_model(2:2).eq.'R') then
c-
c  Distance of nodej from focal point
c-
      dist2 = 0.0
      do 1310 k=1,3
       dist2 = dist2 + (coor(k,nodej) - vcoef(k+6))**2
1310   continue
      if(dist2.gt.0.0) dist2 = sqrt(dist2)
c-
c  Distance of nodei from focal point
c-
      dist1 = 0.0
      do 1320 k=1,3
       dist1 = dist1 + (coor(k,nodei) - vcoef(k+6))**2
1320   continue
      if(dist1.gt.0.0) dist1 = sqrt(dist1)
c-
```

```
c  distr = +ve if nodei is closer to the focal point & -ve otherwise
c-
      distr = dist2 - dist1
c-
c  distc will always be non negative
c-
      if(dist1.gt.0.0 .and. dist2.gt.0.0) then
       do 1330 k=1,3
        distc = distc + (coor(k,nodei) - vcoef(k+6))*
     1             (coor(k,nodej) - vcoef(k+6))/(dist1*dist2)
1330     continue
       distc = 0.5*(dist1 + dist2)*(acos(distc))
      else
       distc = 0.0
      endif
c=====
c  Compute the distance between the two points relative to a vector
c  The direction is given by (vcoef(6),vcoef(7),vcoef(8))
c=====
     else if(ccc_model(2:2).eq.'V') then
c-
c  Projection of the vector (nodei to nodej) on the unit direction vector
c  representing the flow direction
c  distr = +ve if nodei is closer to the focal point & -ve otherwise
c-
      distr = 0.0
      do 1410 k=1,3
       distr = distr + (coor(k,nodej) - coor(k,nodei))*vcoef(k+6)
1410   continue
c-
c  Distance of nodej to nodei across the direction of flow
c  distc will always be non negative
c-
      distc = 0.0
      do 1420 k=1,3
       distc = distc + (coor(k,nodej) - coor(k,nodei))**2
1420   continue
      distc = distc - distr**2
      if(distc.gt.0.0) then
       distc = sqrt(distc)
      else
       distc = 0.0
      endif
c=====
c  Trap Unknown model error
c=====
```

```
      else
        write (iw,*) ' *Error in CCC_DIST unknown correlation model ',
     1             ccc_model(1:2)
        ierr = 2
      endif
      if(ierr.gt.1) stop
c------------------------------End of CCC_DIST--------------------------------
      return
      end
      subroutine ccc_logo(iw)
c==============================================================
===============
c
c  Print logo specifying code upgrade information
c
c
c  Called By CCC_INIT  -  Cross correlation initializer
c
c  Calls     none
c
c
c
c  Written  By Amitabha DebChaudhury        On 05-10-94
c
c  Modified By Amit                         On 05-23-94
c
c-------------------------------------------------------------------------
c Given
c  Name            Type   Description
c ---------        -------- ----------------
c  iw              Integer Unit number for output
c
c
c Returns None
c
c Common  None
c
c Local Variables Defined as needed
c
c==============================================================
===============
      implicit none
      integer  iw
c
      write (iw,700)
      write (iw,701)
```

```
700  format(//,5x,
 1'=============================================================',/5x,
   1'                                        ',/5x,
   1' User Defined Cross-Correlation Models Implemented on   ',/5x,
   1'                                        ',/5x,
   1'            N E S S U S                  ',/5x,
   1'                                        ',/5x,
   1'             [ Ver 1.0b ]                ',/5x,
   1'                                        ',/5x,
   1' Developed By Amitabha DebChaudhury  at Rocketdyne     ',/5x,
   1' Last Modified On 07-05-94                    ',/5x,
   1'                                        ',/5x,
   1' Available Models are                        ',/5x,
   1'                                        ',/5x,
   1'  UNCORR - Uncorrelated between nodes               ',/5x,
   1'  CORR   - Fully Correlated between nodes           ',/5x,
   1'                                        ')
701  format(5x,
   1' D**    - Only distance dependent               ',/5x,
   1' F**   - Distance & Frequency dependent            ',/5x,
   1'                                        ',/5x,
   1' *A*    - Absolute Distance                  ',/5x,
   1' *R*    - Distance relative to a focal point        ',/5x,
   1' *V*    - Distance relative to a vector (along & cross',/5x,
   1'                                        ',/5x,
   1' **L   - Linear decay                        ',/5x,
   1' **E   - Exponential decay                      ',/5x,
   1'                                        ',/5x,
   1'                                        ',/5x,
   1'                                        ',/5x,
   1'=============================================================',//)
c-----------------------------End of CCC_LOGO--------------------------------
   return
   end
   subroutine CCC_FDD(rho,coor,omega,vcoef,rcoef,ccc_model,icoef,
  1      nvcoef,nrcoef,nicoef,nodei,nodej,nnode,maxcrd,iw,ierr)
c=============================================================
==============
c
c  Defines the cross correlation between nodei & nodej based on a frequency
c  & distance dependent model
c
c
c  Called By UPSRHO   - Main control to set cross correlation
c
```

```
c Calls    CCC_DIST  -  Compute the distance between two points
c
c
c
c Written  By Amitabha DebChaudhury        On 05-02-94
c
c Modified By Amit                   On 05-23-94
c
c---------------------------------------------------------------------------
c Given
c Name             Type   Description
c ---------        -------- ----------------
c coor(maxcrd,nnode)  Real*8  Nodal co-ordinates
c omega            Real*8  Frequency (Radians/sec) for this specral point
c vcoef(nvcoef)      Real*8  Parameters defining the cross correlation model
c rcoef(nrcoef)      Real*8  Parameters computed or defined inside  ccc_INI
c icoef(nicoef)      Integer Parameters computed or defined inside  ccc_INI
c ccc_model         Char*80 Correlation Model ID
c nrcoef           Integer Size of array rcoef()
c nvcoef           Integer Size of array vcoef()
c nodei            Integer The node Id of the 1st node
c nodej            Integer The node Id of the 2nd node
c nnode            Integer The Maximum Node ID
c maxcrd           Integer Max no. of attributes in a node
c iw              Integer Unit number for output
c
c Returns
c Name             Type   Description
c ---------        -------- ----------------
c rho(1)           Real*8  Real part of the cross corrln coeffn
c rho(2)           Real*8  Immaginary part of the cross corrln coeffn
c ierr            Integer Error flag (0 - no error)
c
c
c Common  None
c
c Local Variables Defined as needed
c
c==============================================================
===============
      implicit none
      character*80 ccc_model
      real*8     distr,distc,dum0,dum1,dum2,dum3,
     1           rho,coor,omega,vcoef,rcoef
      integer    icoef,nvcoef,nrcoef,nicoef,nodei,nodej,nnode,
     2           maxcrd,iw,ierr
```

```
c    3          ,icall
c     save icall
c
      dimension coor(maxcrd,nnode),rho(2),
     1  vcoef(nvcoef),rcoef(nrcoef),icoef(nicoef)
c     data icall / 0 /
c==========
c  Compute the distance between the two points based on various assumption
c==========
      ierr = 0
      call CCC_DIST(distr,distc,coor,vcoef,ccc_model,nvcoef,
     1               nodei,nodej,nnode,maxcrd,iw,ierr)
c--
c  Incorporate the phase shift
c--
      dum0 = omega*distr/vcoef(10)
      rho(1) =  cos(dum0)
      rho(2) = -sin(dum0)
c--
c  Incorporate decay along flow direction
c--
      if(icoef(1).gt.0) then
       dum1 = -rcoef(1)*omega**icoef(1)
      else
       dum1 = -rcoef(1)
      endif
c
      if(icoef(2).gt.0) then
       dum1 = dum1*abs(distr)**icoef(2)
      else
       dum1 = dum1*distr
      endif
c--
c  Incorporate decay across flow direction
c--
      if(icoef(3).gt.0) then
       dum2 = -rcoef(2)*omega**icoef(3)
      else
       dum2 = -rcoef(2)
      endif
c
      if(icoef(4).gt.0) then
       dum2 = dum2*abs(distc)**icoef(4)
      else
       dum2 = dum2*distc
      endif
```

```
c--
c  Obtain the final coefficients
c--
      dum3 = exp(dum1+dum2)
      rho(1) = rho(1)*dum3
      rho(2) = rho(2)*dum3
c       icall = icall +1
c       write (iw,500) icall,nodei,nodej,omega,rho(1),rho(2),
c      1 distr,distc,dum0,dum1,dum2,dum3
c500   format(' icall,nodei,nodej,omega,rho(1),rho(2), ',
c      1 'distr,distc,dum0,dum1,dum2,dum3 ',3i5,1p3e12.5,/,5x,
c      2 1p6e10.3)
c------------------------------End of CCC_FDD----------------------------------
      return
      end
      SUBROUTINE UZFUNC( ILPRNT, ICONSL, IRMODL, ICMETH, NPCOEF,
     +                PFCOEF, FEMRES, NFMVR , VALIV , NRNVAR,
     +                VALDV , IERR)
c--------|---------|---------|---------|---------|---------|---------|--
C
C USER SUBROUTINE TO COMPUTE THE Z-FUNCTION.  THIS ROUTINE IS
USED FOR
C COMBINED STRESS & RESISTANCE MODELING AND FOR CLOSED-FORM
Z-FUNCTIONS.
C
C
C ARGUMENTS (S-SENT, R-RETURNED):
C
C    ILPRNT - S - OUTPUT FILE UNIT NUMBER
C    ICONSL - S - SCREEN UNIT NUMBER
C    IRMODL - S - RESISTANCE MODEL NUMBER
C    ICMETH - S - COMPUTATIONAL METHOD (0-NONE,1-FEM)
C    NPCOEF - S - NUMBER OF USER-INPUT COEFFICIENTS
C    PFCOEF - S - USER-INPUT COEFFICIENTS
C    FEMRES - S - ARRAY OF FEM RESPONSE VARIABLES
C     NFMVR - S - NUMBER OF FEM RESPONSE VARIABLES
C     VALIV - S - VALUES OF THE INDEPENDENT RANDOM VARIABLES
C    NRNVAR - S - NUMBER OF INDEPENDENT RANDOM VARIABLES
C     VALDV - R - VALUE OF THE DEPENDENT RANDOM VARIABLE
C      IERR - R - ERROR FLAG (RETURN GREATER THAN ZERO ON ERROR)
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      PARAMETER(MaxNIRV=25, MaxNDRV=15)
      PARAMETER (MRANV=100)
C--------------------------------------------------------
C    PERTURBED X POINT
```

```
      COMMON /PRTPT / XPRTPT(MRANV)
C-------------------------------------------------------
C   RANDOM VARIABLE NAMES SO USER CAN IDENTIFY VARIABLES
      CHARACTER*8 RVNAME
      COMMON /RVNAME/ RVNAME(MRANV)
C-------------------------------------------------------
C   USER COEFFICIENTS
      COMMON /USRCOF/ IUNIT, JPERI, NCOEF, VCOEF(10)
C-------------------------------------------------------
C   PERTURBATION COUNTER
      common /usrprt/ jpvaru
C-------------------------------------------------------
      DIMENSION FEMRES(NFMVR), VALIV(NRNVAR), PFCOEF(NPCOEF)
C-------------------------------------------------------
      logical bbb_mean
      integer dist_opt,fat_opt
      double precision Kt,mean_par
      dimension fat_par(31),mean_par(10),dist_par(10),tensile(5),
     .        upscoef(11)
      character*40 dist_file
C
      data pi   /3.14159265/
      data init / -99 /
      save flow_m_ref,flow_v_ref,init
C
C.......................................................................
C
C
C BRANCH TO THE SELECTED MODEL
C
      IF (IRMODL.LE.0) GOTO 9999
      GOTO( 100 ), IRMODL
C
C UNDEFINED MODEL
C
      WRITE(ICONSL,10) IRMODL
      WRITE(ILPRNT,10) IRMODL
 10  FORMAT(/,' [UZFUNC] - ERROR - RESISTANCE MODEL ',I5,' HAS NOT',
   +        ' BEEN DEFINED IN SUBROUTINE UZFUNC.')
      IERR = IERR + 1
      GOTO 9999
c
 100 CONTINUE
c
      rms =femres(1)
      rmsd=femres(2)
```

```
C
C    modified by RAJ 04/10/95
C    the expected frequecy calc. moved from below
C    to this location to make
C    the expected frequecy computations before any scale factor
C    is applied
      fexp=rmsd/rms*0.5d0/pi
C
C    modified by RAj 041095
C    address is different because all computational variables are
C    sequenced first
C
C    Phi =valiv(8)
      Phi =valiv(12)
      write(*,'(a)') 'from UZFUNC'
      iout=6
      ind_fat    =nint(pfcoef(3))
      dist_opt   =nint(pfcoef(ind_fat))
      dist_par(1)=0.0d0
      dist_par(3)=pfcoef(ind_fat+1)
      fat_opt    =6
      npoint     =nint(pfcoef(ind_fat+2))
      nfat_par   =npoint*2+1
      fat_par(1) =0.0d0
      do i=1,npoint
       ii=(i-1)*2+2
       fat_par(ii  )=pfcoef(ind_fat+ii+1)
       fat_par(ii+1)=pfcoef(ind_fat+ii+2)
      enddo
      ind_fat    =ind_fat+npoint*2+3
      FTY        =pfcoef(ind_fat  )
      FTU        =pfcoef(ind_fat+1)
      T          =pfcoef(ind_fat+2)
c    half segment loaded
      fac_PSD    =pfcoef(ind_fat+3)
c    cyclic load factor
      fac_cycl   =pfcoef(ind_fat+4)
c    hybrid model load factor
      fac_hyb    =pfcoef(ind_fat+5)
C
C    modified by RAJ 041095
C    This kt is coming in as a random variable now with
C    address location as 13.
C    Kt         =pfcoef(ind_fat+6)
      Kt         =valiv(13)
      tensile(2)=FTY
```

```
      tensile(3)=FTU
      s_mean   =FTY
      bbb_mean  =.false.
      mean_opt  =1
c
      if (init.eq.-99) then
       init=0
       call NESCLSICM(vcoef,pfcoef,upscoef)
       flow_v_ref=upscoef(10)
       flow_m_ref=upscoef(11)
      else
       call NESCLSICM(vcoef,pfcoef,upscoef)
       flow_v=upscoef(10)
       flow_m=upscoef(11)
       PSDratio=flow_m*flow_m/flow_m_ref/flow_m_ref*flow_v/flow_v_ref
       rms=rms*sqrt(PSDratio)
      endif
c     expected frequency calculation moved up
C      modified by RAJ 041095 see comment earlier
C
C      fexp=rmsd/rms*0.5d0/pi
      dist_par(2)=rms*fac_PSD*fac_cycl*fac_hyb
c
      factor=Kt
      do i=2,nfat_par-1,2
       fat_par(i)=fat_par(i)*Phi
      enddo
      call fatigue_echo(iout,fexp,T,s_mean,factor,
     .             dist_opt,dist_par,dist_file,
     .             fat_opt,nfat_par,fat_par,
     .             bbb_mean,mean_opt,mean_par,
     .             tensile)
C
C     modified by RAJ 4/13/95
C     Argument list made consistent with fatigue_calc routines
C      added npoint
      call fatigue_calc
     .            (iout,fexp,T,s_mean,factor,
     .             dist_opt,dist_par,dist_file,
     .             fat_opt,nfat_par,fat_par,
     .             bbb_mean,mean_opt,mean_par,
     .             tensile,damage,npoint)
      write(*,'(a,e15.5)') 'Damage= ',damage
      valdv=damage
c
      GOTO 9999
```

```
c
 9999 CONTINUE
    RETURN
    END
```

cros_corr_inp file read from UPSHRO to activate different correlation models :

F - Frequency and distance dependent correlation model
  Other options for this field are
  C - correlated
  U - uncorrelated
  D - distance dpendent correlation

V - Unit vector determined the direction
  Other Options for this field are
  A - absolute distance between points
  R - relative distance to a focal point
  V - unit vector

E - Exponential decay
  Other options
  L - linear decay

```
FVE
0 1 0 1
CORR
0 0 0 0
```

Appendix E
Fatigue Damage Computation Module

```
c--------|---------|---------|---------|---------|---------|---------|--
c
c              FATIGUE CORE ROUTINES:
c
c--------|---------|---------|---------|---------|---------|---------|--
c
      subroutine fatigue_batch_input
     .           (iin,iout,device,fexp,T,s_mean,factor,
     .            dist_opt,dist_par,hist_file,
     .            fat_opt,nfat_par,fat_par,
     .            bbb_mean,mean_opt,mean_par,
     .            tensile)
c--------|---------|---------|---------|---------|---------|---------|--
c
c     Arguments described in subroutine fatigue_calc
c     Reads fatigue problem batch input
c
c--------|---------|---------|---------|---------|---------|---------|--
c
      integer mx_fatpar
      parameter (mx_fatpar=51)
c
      integer lent
c
      integer ibegin,iend,iin,iscr,istart
      logical bbb_mean,in_use
      character*5 device,system
      character*10 format
      integer dist_opt,fat_opt,mean_opt,nfat_par
      double precision factor,fexp,s_mean,T,fat_par(mx_fatpar),
     .           mean_par(10),
     .           dist_par(10),tensile(5)
      character*40 hist_file
c
      common /conf/ system
c
      integer eof,ii
      character*80 line
c
      tensile(2)=0.0d0
      tensile(3)=0.0d0
      factor=1.0d0
```

```
      device='    '
      if (system.eq.'pc   ') then
       format='(1x,a)'
      else
       format='(a)'
      endif
c
      iscr=45
      inquire(iscr,opened=in_use)
      do while (in_use)
       iscr=iscr+1
       inquire(iscr,opened=in_use)
      enddo
      read(iin,'(a)',iostat=eof) line
      do while (eof.eq.0)
       write(iout,format) line(1:79)
c
       if (line(1:1).ne.'C') then
c
        if (index(line,'LOAD SPECTRUM').ne.0) then
         if (index(line,'RAYLEIGH').ne.0) then
          do i=1,3
           read(iin,'(a)') line
           write(iout,format) line(1:79)
           open(iscr,file='scratch',status='unknown')
           write(iscr,format) line(index(line,'=')+1:80)
           rewind(iscr)
           read(iscr,*) dist_par(i)
           close(iscr)
          enddo
          read(iin,'(a)') line
          write(iout,format) line(1:79)
          open(iscr,file='scratch',status='unknown')
          write(iscr,format) line(index(line,'=')+1:80)
          rewind(iscr)
          read(iscr,*) fexp
          close(iscr)
          read(iin,'(a)') line
          write(iout,format) line(1:79)
          open(iscr,file='scratch',status='unknown')
          write(iscr,format) line(index(line,'=')+1:80)
          rewind(iscr)
          read(iscr,*) T
          close(iscr)
          dist_opt=1
         endif
```

```
  if (index(line,'FDAS').ne.0) then
   read(iin,'(a)') line
   write(iout,format) line(1:79)
   iend=lent(line)
   ibegin=1
   do while (line(ibegin:ibegin).eq.' ')
    ibegin=ibegin+1
   enddo
   hist_file=line(ibegin:iend)
   read(iin,*) dist_par(1)
   write(iout,'(f4.1,a)') dist_par(1),' % SCREENING LEVEL'
   dist_opt=2
  endif
 endif
c
 if ((index(line,'MEAN STRESS').ne.0).and.
.   (index(line,'='          ).ne.0)) then
  open(iscr,file='scratch',status='unknown')
  write(iscr,format) line(index(line,'=')+1:80)
  rewind(iscr)
  read(iscr,*) s_mean
  close(iscr)
 endif
c
 if (index(line,'FACTOR').ne.0) then
  open(iscr,file='scratch',status='unknown')
  write(iscr,format) line(index(line,'=')+1:80)
  rewind(iscr)
  read(iscr,*) factor
  close(iscr)
 endif
c
 if (index(line,'MEAN STRESS CORRECTION').ne.0) then
  bbb_mean=(index(line,'BIN-BY-BIN').ne.0)
  if (index(line,'LINEAR GOODMAN').ne.0) then
   mean_opt=1
  else
   mean_opt=2
   read(iin,*) mean_par(1),mean_par(2),mean_par(3)
  endif
 endif
c
 if (index(line,'FATIGUE CURVE').ne.0) then
  if (index(line,'MULTI-SECTION').ne.0) then
   fat_opt=6
   npoint=0
```

```
      read(iin,'(a)') line
      write(iout,format) line(1:79)
      do while(index(line,'ENDURANCE').eq.0)
       npoint=npoint+1
       ii=2+(npoint-1)*2
       open(iscr,file='scratch',status='unknown')
       write(iscr,format) line(index(line,'=')+1:80)
       rewind(iscr)
       read(iscr,*) fat_par(ii),fat_par(ii+1)
       close(iscr)
       read(iin,'(a)') line
       write(iout,format) line(1:79)
      enddo
      nfat_par=2*npoint+1
      if (index(line,'=').ne.0) then
       open(iscr,file='scratch',status='unknown')
       write(iscr,format) line(index(line,'=')+1:80)
       rewind(iscr)
       read(iscr,*) fat_par(1)
       close(iscr)
      else
       fat_par(1)=0.0d0
      endif
     endif
    endif
c
    if (index(line,'TENSILE PROPERTIES').ne.0) then
     do while ((tensile(2).eq.0.0d0).or.(tensile(3).eq.0.0d0))
      read(iin,'(a)') line
      write(iout,format) line(1:79)
      if (index(line,'E').ne.0) then
       open(iscr,file='scratch',status='unknown')
       write(iscr,format) line(index(line,'=')+1:80)
       rewind(iscr)
       read(iscr,*) tensile(1)
       close(iscr)
      endif
      if (index(line,'FTY').ne.0) then
       open(iscr,file='scratch',status='unknown')
       write(iscr,format) line(index(line,'=')+1:80)
       rewind(iscr)
       read(iscr,*) tensile(2)
       close(iscr)
      endif
      if (index(line,'FTU').ne.0) then
       open(iscr,file='scratch',status='unknown')
```

```
          write(iscr,format) line(index(line,'=')+1:80)
          rewind(iscr)
          read(iscr,*) tensile(3)
          close(iscr)
         endif
        enddo
       endif
      endif
c
      if (index(line,'DEVICE').ne.0) then
       istart=index(line,'=')+1
       do while (line(istart:istart).eq.' ')
        istart=istart+1
       enddo
       device=line(istart:istart+4)
      endif
c
      read(iin,'(a)',iostat=eof) line
     enddo
c
     return
     end
c
     subroutine fatigue_echo
    .         (iout,fexp,T,s_mean,factor,
    .          dist_opt,dist_par,hist_file,
    .          fat_opt,nfat_par,fat_par,
    .          bbb_mean,mean_opt,mean_par,
    .          tensile)
c--------|---------|---------|---------|---------|---------|---------|--
c
c    Arguments described in subroutine fatigue_calc
c    Prints fatigue problem input
c
c--------|---------|---------|---------|---------|---------|---------|--
c
     implicit none
c
     integer iout
     logical bbb_mean
     integer dist_opt,fat_opt,mean_opt,nfat_par
     double precision factor,fexp,s_mean,T,fat_par(nfat_par),
    .         mean_par(10),
    .         dist_par(10),tensile(5)
     character*40 hist_file
c
```

```
      integer i,ii,npoint
c
      if (dist_opt.eq.1) then
       write(iout,'(a)') 'LOAD SPECTRUM: RAYLEIGH'
       write(iout,'(a,f13.3  )') 'SINE              =',dist_par(1)
       write(iout,'(a,f13.3  )') '1 SIGMA           =',dist_par(2)
       write(iout,'(a,f13.3,a)') 'TAIL              =',dist_par(3),
     .                   ' SIGMAS'
       write(iout,'(a,f13.3  )') 'EXPECTED FREQUENCY =',fexp
       write(iout,'(a,f13.3  )') 'DURATION          =',T
      endif
      if (dist_opt.eq.2) then
       write(iout,'(a)') 'LOAD SPECTRUM: FDAS'
       write(iout,'(a)')
     . 'HISTOGRAM FILE NAME: '//hist_file//' HISTOGRAM'
       write(iout,'(a)') hist_file
       write(iout,'(f4.1,a)') dist_par,' % SCREENING LEVEL'
      endif
      if (dist_opt.eq.3) then
      endif
c
      if (fat_opt.eq.1) then
      endif
      if (fat_opt.eq.2) then
      endif
      if (fat_opt.eq.3) then
      endif
      if (fat_opt.eq.4) then
      endif
      if (fat_opt.eq.5) then
      endif
c
      write(iout,'(a,f13.3)') 'MEAN STRESS       =',s_mean
      write(iout,'(a,f13.3)') 'FACTOR            =',factor
      if (bbb_mean) then
       if (mean_opt.eq.1) then
        write(iout,'(a)')
     .     'MEAN STRESS CORRECTION: LINEAR GOODMAN '//
     .     'BASED ON BIN-BY-BIN'
       endif
       if (mean_opt.eq.2) then
        write(iout,'(a)')
     .     'MEAN STRESS CORRECTION: NONLINEAR HEIDMANN '//
     .     'BASED ON BIN-BY-BIN'
        write(iout,'(3f10.4,a)') mean_par(1),mean_par(2),mean_par(3),
     .  ' (CUTOFF, W0, W1)'
```

```
      endif
     else
      if (mean_opt.eq.1) then
       write(iout,'(a)')
     .     'MEAN STRESS CORRECTION: LINEAR GOODMAN '//
     .     'BASED ON MAXIMUM AMPLITUDE'
      endif
      if (mean_opt.eq.2) then
       write(iout,'(a)')
     .     'MEAN STRESS CORRECTION: NONLINEAR HEIDMANN '//
     .     'BASED ON MAXIMUM AMPLITUDE'
       write(iout,'(3f10.4,a)') mean_par(1),mean_par(2),mean_par(3),
     .  ' (CUTOFF, W0, W1)'
      endif
     endif
c
     if (fat_opt.eq.6) then
      write(iout,'(a)')
     .    'FATIGUE CURVE: MULTI-SECTION '
      npoint=(nfat_par-1)/2
      do i=1,npoint
       ii=(i-1)*2+2
       write(iout,'(f20.3,f13.3)') fat_par(ii),fat_par(ii+1)
      enddo
      if (fat_par(1).gt.0) then
       write(iout,'(a,f13.3)') 'ENDURANCE LIMIT: ',fat_par(1)
      else
       write(iout,'(a)') 'NO ENDURANCE LIMIT'
      endif
     endif
c
     write(iout,'(a)') 'TENSILE PROPERTIES:'
     if (tensile(1).gt.0.0d0) write(iout,'(a,e15.5)')
     .  'ELASTIC MODULUS    = ',tensile(1)
     write(iout,'(a,f13.3)')'FTY             =',tensile(2)
     write(iout,'(a,f13.3)')'FTU             =',tensile(3)
c
     return
     end
c
     subroutine fatigue_calc
     .           (iout,fexp,T,s_mean,factor,
     .            dist_opt,dist_par,hist_file,
     .            fat_opt,nfat_par,fat_par,
     .            bbb_mean,mean_opt,mean_par,
     .            tensile,damage,npoint)
```

```
c--------|---------|---------|---------|---------|---------|---------|--
c
c   fexp     (I): expected frequency (input when dist_opt.ne.2)
c   T        (I): duration
c   s_mean   (I): mean stress
c   factor   (I): amplification factor (Kt)
c   dist_opt (I): distribution type
c             1 - Rayleigh
c             2 - FDAS histogram
c             3 - lognormal
c   dist_par (I): distribution parameters
c             if dist_opt=1 - sine, 1 sigma, # of sigmas
c             if dist_opt=3 - sine, mean, sigma, # of sigmas
c   hist_file (I): histogram file name, applicable only if dist_opt=2
c   fat_opt  (I): fatigue curve representation option
c             1 - strain range based    full range curve fit
c             2 - strain range based    LCF only  curve fit
c             3 - stress amplitude based HCF only  curve fit
c             4 - strain range based    full range tabular
c             5 - strain range based    LCF only  tabular
c             6 - stress amplitude based HCF only  tabular
c   nfat_par (I): number of fatigue curve parameters
c   fat_par  (I): fatigue curve parameters
c             if fat_opt=1  endur,BBe,be,CCe,ce
c             if fat_opt=2  BBe,be
c             if fat_opt=3  endur,CCs,cs
c             if fat_opt=4  endur,de1,N1,de2,N2,...,
c                           Ni strictly monotonic increasing,
c                           initialize unused points to zero
c             if fat_opt=5  de1,n1,de2,n2,...
c             if fat_opt=6  endur,ds1,N1,ds2,N2,...
c                           Ni strictly monotonic increasing,
c                           initialize unused points to zero
c   bbb_mean  (I): bin-by-bin mean stress correction
c   mean_opt  (I): mean stress correction option
c             1 - Linear Goodman
c             2 - Nonlinear Heidmann
c   mean_par  (I): mean stress correction parameters
c             if mean_opt=2 w0, w1, g_cutoff
c   tensile  (I): tensile properties
c             tensile(1)=elastic modulus
c             tensile(2)=FTY
c             tensile(3)=FTY
c   damage   (O): if damage>0,  calculated damage
c             if damage<0,  factor of safety= abs(damage)
c
```

```
c     Calculates fatigue damage due to spectrum loading
c
c--------|---------|---------|---------|---------|---------|---------|--
c
      implicit none
c
      integer mx_dist,nbin
      parameter (mx_dist=600,nbin=210)
c
      integer iout
      logical bbb_mean
      integer dist_opt,fat_opt,mean_opt,nfat_par
      double precision factor,fexp,s_mean,T,fat_par(nfat_par),
     .         mean_par(10),mean_adjust,mean_correct,
     .         dist_par(10),damage,tensile(5)
      character*40 hist_file
c
      logical in_use,odd_points
      integer i,j,jmax,npoint,iscr
      double precision acc_meas,dam_0,dam_1,dam_2,dam_rat,endur,
     .         hist(mx_dist),hcur,h,int,n_act,ncyc,Nfm,
     .         s_alt,s_alt_eq,s_alt_mn,s_alt_mx,s_mean_adj
c
      iscr=36
      inquire(iscr,opened=in_use)
      do while (in_use)
       iscr=iscr+1
       inquire(iscr,opened=in_use)
      enddo
      open(iscr,file='scratch.fat',status='unknown')
c
      npoint=nbin+1
      ncyc  =fexp*T
      call histogram
     .  (iout,ncyc,dist_opt,dist_par,hist_file,tensile,hist,npoint,
     .   s_alt_mn,s_alt_mx)
      odd_points=(nint(npoint/2.0)*2.ne.npoint)
c
      if ((fat_opt.eq.1).or.
     .  (fat_opt.eq.3).or.
     .  (fat_opt.eq.4).or.
     .  (fat_opt.eq.6)) then
       endur=fat_par(1)
      else
       endur=0.0d0
      endif
```

```
      s_mean_adj=mean_adjust
     .       (s_mean,s_alt_mx,factor,tensile)
      s_alt_eq  =mean_correct
     .       (s_alt_mx,s_mean_adj,factor,mean_opt,mean_par,tensile)
      if (s_alt_eq.lt.endur) then
       damage=-endur/s_alt_mx/factor
      else
c
       dam_0    =0.0d0
       dam_1    =0.0d0
       dam_2    =0.0d0
       dam_rat  =0.0d0
       i        =0
       s_alt    =0.0d0
       h        =(s_alt_mx-s_alt_mn)/(npoint-1)
c
       i   =i+1
       s_alt=s_alt_mn
       if (s_alt.gt.0) then
        hcur=hist(i)
        call bin_calc
     .       (i,iout,iscr,s_alt,s_alt_eq,s_mean_adj,
     .        factor,tensile,
     .        fat_opt,nfat_par,fat_par,
     .        bbb_mean,mean_opt,mean_par,hcur,
     .        Nfm,n_act,dam_0,dam_1,int,dam_rat)
        if (odd_points) dam_2=dam_2+int
       endif
       jmax=nint((npoint-3)/2.0)
       do j=1,jmax
        i   =i+1
        s_alt=s_alt+h
        hcur =hist(i)
        call bin_calc
     .       (i,iout,iscr,s_alt,s_alt_eq,s_mean_adj,
     .        factor,tensile,
     .        fat_opt,nfat_par,fat_par,
     .        bbb_mean,mean_opt,mean_par,hcur,
     .        Nfm,n_act,dam_0,dam_1,int,dam_rat)
        if (odd_points) dam_2=dam_2+int*4.0d0
        i   =i+1
        s_alt=s_alt+h
        hcur =hist(i)
        call bin_calc
     .       (i,iout,iscr,s_alt,s_alt_eq,s_mean_adj,
     .        factor,tensile,
```

```
     .         fat_opt,nfat_par,fat_par,
     .         bbb_mean,mean_opt,mean_par,hcur,
     .         Nfm,n_act,dam_0,dam_1,int,dam_rat)
        if (odd_points)dam_2=dam_2+int*2.0d0
       enddo
       if (odd_points) then
        i   =i+1
        s_alt=s_alt+h
        hcur =hist(i)
        call bin_calc
     .        (i,iout,iscr,s_alt,s_alt_eq,s_mean_adj,
     .         factor,tensile,
     .         fat_opt,nfat_par,fat_par,
     .         bbb_mean,mean_opt,mean_par,hcur,
     .         Nfm,n_act,dam_0,dam_1,int,dam_rat)
        dam_2=dam_2+int*4.0d0
       endif
       i   =i+1
       s_alt=s_alt_mx
       hcur =hist(i)
       call bin_calc
     .        (i,iout,iscr,s_alt,s_alt_eq,s_mean_adj,
     .         factor,tensile,
     .         fat_opt,nfat_par,fat_par,
     .         bbb_mean,mean_opt,mean_par,hcur,
     .         Nfm,n_act,dam_0,dam_1,int,dam_rat)
       if (odd_points) dam_2=dam_2+int
c
       if (odd_points) dam_2=dam_2/3
       if (odd_points) then
        damage=dam_2
        acc_meas=dam_2/dam_1
       else
        damage=dam_1
        acc_meas=dam_1/dam_0
       endif
       write(iout,'(a)')
       write(iout,'(a,f5.2)')
     .     '   Numerical integration accuracy measure:',acc_meas
       write(iout,'(a)')
      endif
c
      close(iscr)
c
      return
      end
```

```
c
c--------|---------|---------|---------|---------|---------|---------|--
      subroutine bin_calc
     .         (i,iout,iscr,s_alt,s_alt_eq,s_mean_adj,
     .          factor,tensile,
     .          fat_opt,nfat_par,fat_par,
     .          bbb_mean,mean_opt,mean_par,hcur,
     .          Nfm,n_act,dam_0,dam_1,int,dam_rat)
c
c
c
c--------|---------|---------|---------|---------|---------|---------|--
c
      implicit none
c
      logical bbb_mean
      integer iout,iscr,fat_opt,nfat_par,mean_opt
      double precision s_alt,s_alt_eq,s_mean_adj,
     .                 factor,tensile(5),
     .                 fat_par,
     .                 mean_par(10),hcur,
     .                 Nfm,n_act,dam_0,dam_1,dam_rat
c
      integer i,iter,itermx
      double precision big,mean_adjust,mean_correct,
     .                 corr,dam_rat_p,den,dFF,eps,err,FF,FTU,
     .                 G,G_thres,int,lnsmrat,
     .                 ln10,Nf0_eval,slope,smrat,w0,w1,wr4
c
      data itermx,eps,big /100000,0.00001,1.0d10/
c
      if (bbb_mean)
     . s_mean_adj=mean_adjust
     .          (s_mean_adj,s_alt,factor,tensile)
      s_alt_eq  =mean_correct
     .          (s_alt,s_mean_adj,factor,mean_opt,mean_par,tensile)
      if (mean_opt.eq.1)
     . call cyc_fat(fat_opt,nfat_par,fat_par,s_alt_eq,Nfm,slope,iout)
      if (mean_opt.eq.2)  then
       FTU    =tensile(3)
       G_thres=mean_par(1)
       w0=mean_par(2)
       w1=mean_par(3)
       ln10=log(10.0d0)
       iter=1
       slope=1.0d0
```

```
        call cyc_fat(fat_opt,nfat_par,fat_par,s_alt_eq,Nfm,slope,iout)
        G=w0+w1*log10(Nfm)
        if (G.lt.G_thres) G=G_thres
        smrat=s_mean_adj/FTU
        den=1.0d0-smrat**G
        s_alt_eq=s_alt/den
        slope=1.0d0
        call cyc_fat
     .  (fat_opt,nfat_par,fat_par,s_alt_eq,Nf0_eval,slope,iout)
        FF=Nf0_eval-Nfm
        lnsmrat=log(smrat)
        dFF=
     .  slope*s_alt/den/den*lnsmrat*smrat**G*w1/Nfm/ln10-1.0d0
        corr=-FF/dFF
        Nfm=Nfm+corr
        err=abs(corr)/Nfm
        do while ((err.gt.eps).and.(iter.le.itermx))
         iter=iter+1
         G=w0+w1*log10(Nfm)
         if (G.lt.G_thres) G=G_thres
         smrat=s_mean_adj/FTU
         den=1.0d0-(smrat)**G
         s_alt_eq=s_alt/den
         slope=1.0d0
         call cyc_fat
     .   (fat_opt,nfat_par,fat_par,s_alt_eq,Nf0_eval,slope,iout)
          FF=Nf0_eval-Nfm
         lnsmrat=log(smrat)
         dFF=
     .   slope*s_alt/den/den*lnsmrat*smrat**G*w1/Nfm/ln10-1.0d0
         corr=-FF/dFF
         Nfm=Nfm+corr
         err=abs(corr)/Nfm
        enddo
        if ((err.gt.eps).and.(iter.gt.itermx)) then
         write(*,*) '***** ERROR *****'
         write(*,*)
     .   'nonlinear mean stress correction iteration failed at'//
     .   'alternating stress of ',s_alt
         stop
        endif
c        write(*,'(i5,4f10.3,2e15.2)')
c    .       i,s_alt,G,s_mean_adj,s_alt_eq,Nfm
       endif
       int     =hcur/Nfm
       n_act   =hcur
```

```
      dam_rat_p =dam_rat
      dam_rat   =n_act/NFm
      dam_0     =dam_0+dam_rat
      dam_1     =dam_1+0.5*(dam_rat_p+dam_rat)
c
      if (Nfm.lt.big) then
       wr4=Nfm
      else
       wr4=big
      endif
      if (dam_0.gt.0.0d0)
     .  write(iscr,'(i5,6e12.3)') i,s_alt,s_alt_eq,
     .                  wr4,n_act,dam_rat,dam_0
c
      return
      end
c
c--------|---------|---------|---------|---------|---------|---------|--
      function mean_adjust
     .      (s_mean,s_alt,factor,tensile)
c
c     s_mean   (I): mean stress
c     s_alt    (I): alternating stress
c     factor   (I): amplification factor (Kt)
c     tensile  (I): tensile properties
c              tensile(1)=elastic modulus
c              tensile(2)=FTY
c              tensile(3)=FTY
c
c     Returns adjusted mean stress that includes Kt
c
c--------|---------|---------|---------|---------|---------|---------|--c
      implicit none
c
      double precision mean_adjust,s_alt,factor,tensile(5)
c
      double precision FTY,FTU,s_alt_f,
     .            s_mean,s_rev_mx,smadj
c
      FTY     = tensile(2)
      FTU     = tensile(3)
c
      s_rev_mx=factor*(s_mean+s_alt)
      if (s_rev_mx.lt.FTY) then
       smadj=s_mean*factor
      else
```

```
      s_alt_f=s_alt*factor
      if (s_alt_f.le.FTY) then
       smadj=FTY-s_alt_f
      else
       smadj=0.0d0
      endif
     endif
     mean_adjust=smadj
c
     return
c
     end
c
c--------|---------|---------|---------|---------|---------|---------|--
     function mean_correct
    .      (s_alt,s_mean,factor,mean_opt,mean_par,tensile)
c
c    s_alt    (I): alternating stress
c    mean_opt (I): mean stress correction option
c             1 - linear Goodman
c             2 - nonlinear Heidmann
c    mean_par (I): mean stress correction parameters
c             if mean_opt=1 FTY, FTU
c             if mean_opt=2 FTY, FTU, w0, w1, g_cutoff
c    tensile  (I): tensile properties
c             tensile(1)=elastic modulus
c             tensile(2)=FTY
c             tensile(3)=FTY
c
c    Returns equivalent alternating stress that includes Kt
c
c--------|---------|---------|---------|---------|---------|---------|--
c
     implicit none
c
     double precision mean_correct,s_alt,s_mean,
    .           factor,mean_par(10),tensile(5)
     integer mean_opt
c
     double precision FTY,FTU,g_cutoff,w0,w1
c
     if (mean_opt.eq.1) then
      FTY     = tensile(2)
      FTU     = tensile(3)
     endif
     if (mean_opt.eq.2) then
```

```
      FTY     = tensile(2)
      FTU     = tensile(3)
      w0      = mean_par(1)
      w1      = mean_par(2)
      g_cutoff = mean_par(3)
     endif
c
     if (mean_opt.eq.1) then
      mean_correct=s_alt*factor/(1.0d0-s_mean/FTU)
     endif
c
     if (mean_opt.eq.2) then
      mean_correct=s_alt*factor/(1.0d0-s_mean/FTU)
     endif
c
     return
     end
c
c--------|---------|---------|---------|---------|---------|---------|--
     subroutine cyc_fat
    .      (fat_opt,nfat_par,fat_par,driver,allow,slope,iout)
c
c    fat_opt (I): fatigue curve representation option
c            1 - strain range based     full range curve fit
c            2 - strain range based     LCF only  curve fit
c            3 - stress amplitude based HCF only  curve fit
c            4 - strain range based     full range tabular
c            5 - strain range based     LCF only  tabular
c            6 - stress amplitude based HCF only  tabular
c    fat_par (I): fatigue curve parameters
c            if fat_opt = 1  endur,BBe,be,CCe,ce
c            if fat_opt = 2  BBe,be
c            if fat_opt = 3  endur,CCs,cs
c            if fat_opt = 4  endur,de1,N1,de2,N2,...,
c                            Ni strictly monotonic increasing,
c                            initialize unused points to zero
c            if fat_opt = 5  de1,n1,de2,n2,...
c            if fat_opt = 6  endur,ds1,N1,ds2,N2,...
c                            Ni strictly monotonic increasing,
c                            initialize unused points to zero
c    driver  (I): cyclic fatigue quantity
c            if fat_opt=1,2,4,5 then strain range
c            if fat_opt=3,6     then stress amplitude
c    allow   (O): allowable number of cycles
c    slope   (O): slope of the fatigue curve returned if input value is 1.0d0
c
```

```
c    Calculates the allowable number of cycles at a cyclic load level
c
c--------|---------|---------|---------|---------|---------|---------|--
c
     implicit none
c
     integer fat_opt,ii,nfat_par
     double precision fat_par(nfat_par),driver,allow,slope
c
     integer i,iout,kount,npoint
     double precision an,an0,an_knee,BBe,be,BBs,bs,BBsi,bsi,CCe,ce,
     .           de,endur,eps,err,f,fp,N1,N2,oobs,salt,salt1,salt2
c
     if (fat_opt.eq.1) then
      endur=fat_par(1)
      de=driver
      if (de.lt.endur) then
       allow=1.0d40
      else
       BBe=fat_par(2)
       be =fat_par(3)
       CCe=fat_par(4)
       ce =fat_par(5)
       an_knee=(BBe/CCe)**(1.0/(ce-be))
       eps   =1.0e-6
       an0   =an_knee
       kount  =0
       err   =1.0
       do while (err.gt.eps)
        kount=kount+1
        if (kount.gt.500) then
         write(iout,*) '***** ERROR from cyc_fat: *****'
         write(iout,*) 'No convergence in cyc_fat'
         stop
        endif
        f =BBe*an0**be+CCe*an0**ce-de
        fp=be*BBe*an0**(be-1.0)+ce*CCe*an0**(ce-1.0)
        an=an0-f/fp
        if (an.lt.0.0) an=10
        err=abs(1.0-an/an0)
        an0=an
       enddo
       allow=an
      endif
     endif
     if (fat_opt.eq.2) then
```

```
  CCe=fat_par(1)
  ce =fat_par(2)
  de =driver
  allow=(de/CCe)**(1.0/ce)
 endif
 if (fat_opt.eq.3) then
  endur=fat_par(1)
  salt =driver
  if (salt.lt.endur) then
   allow=1.0d40
   if (slope.eq.1.0d0) slope=0.0d0
  else
   BBs=fat_par(2)
   bs =fat_par(3)
   bsi=1.0d0/bs
   BBsi=(1.0d0/BBs)**bsi
   allow=BBsi*salt**bsi
   if (slope.eq.1.0d0) slope=BBsi*bsi*salt**(bsi-1.0d0)
  endif
 endif
 if (fat_opt.eq.4) then
 endif
 if (fat_opt.eq.5) then
 endif
 if (fat_opt.eq.6) then
  endur=fat_par(1)
  salt =driver
  if (salt.lt.endur) then
   allow=1.0d40
   if (slope.eq.1.0d0) slope=0.0d0
  else
   npoint=(nfat_par-1)/2
   i   =1
   ii  =(i-1)*2+2
   salt1=fat_par(ii)
   N1   =fat_par(ii+1)
   i   =i+1
   ii  =(i-1)*2+2
   salt2=fat_par(ii)
   N2  =fat_par(ii+1)
   do while ((salt.lt.salt2).and.(i.lt.npoint))
    salt1=salt2
    N1   =N2
    i   =i+1
    ii  =(i-1)*2+2
    salt2=fat_par(ii)
```

```
        N2   =fat_par(ii+1)
       enddo
       bs   =log(salt1/salt2)/log(N1/N2)
       BBs  =salt1/(N1**bs)
       oobs=1.0d0/bs
       allow=(salt/BBs)**oobs
c
c       Although these seem more consistent with other formulations,
c       calculation of BBSi may result in overflow for flat HCF curves
c
c       bsi  =1.0d0/bs
c       BBsi =(1.0d0/BBs)**bsi
c       allow=BBsi*salt**bsi
       if (slope.eq.1.0d0) slope=oobs*(salt/BBs)**(oobs-1.0d0)/BBs
      endif
     endif
c
     return
     end
c
c--------|---------|---------|---------|---------|---------|---------|--
c
     subroutine histogram
    .  (iout,ncyc,dist_opt,dist_par,hist_file,tensile,hist,npoint,
    .   s_alt_mn,s_alt_mx)
c
c    dist_opt  (I): distribution type
c              1 - Rayleigh
c              2 - FDAS histogram
c              3 - lognormal
c    dist_par  (I): distribution parameters
c              if dist_opt=1 - sine, 1 sigma, # of sigmas
c              if dist_opt=2 - sine
c    hist      (O): tabulated probability density function
c    npoint  (I/O): if dist_opt=1,3 then input
c                   if dist_opt=2   then output
c
c    Fills the probability density function vector
c
c--------|---------|---------|---------|---------|---------|---------|--
c
     implicit none
c
     integer mx_dist
     parameter (mx_dist=600)
c
```

```
      integer iout,dist_opt,npoint
      double precision ncyc,dist_par(10),tensile(5),
     .            hist(mx_dist),s_alt_mn,s_alt_mx
      character*40 hist_file
c
      integer lent,nr,nrec
      logical in_use,no_data
      integer eof,i,icol,ii,idist,ier,midbin_cur,midbin_last,
     .     ncol,nevents,screen,screen_list(10)
      double precision deps,dummy,E,epsmin,epsmax,fmin,fmax,h,
     .            nsigma,salt,sine,sigma,rat,tmin,tmax
      character*80 line
c
      if (npoint.gt.mx_dist) then
       write(iout,*) '***** ERROR *****'
       write(iout,*) 'The number points ',npoint,
     .           ' is greater than current allocation of ',
     .           mx_dist
       stop
      endif
      if (dist_opt.eq.1) then
       sine =dist_par(1)
       sigma =dist_par(2)
       nsigma=dist_par(3)
       h   =nsigma*sigma/(npoint-1)
       hist(1)=0.0d0
       do i=2,npoint
        salt=(i-1)*h
        rat=salt/sigma
        hist(i)=rat/sigma*exp(-0.5d0*rat*rat)*ncyc*h
       enddo
       s_alt_mn=sine
       s_alt_mx=sine+nsigma*sigma
      endif
c
      if (dist_opt.eq.2) then
       idist=25
       inquire(idist,opened=in_use)
       do while (in_use)
        idist=idist+1
        inquire(idist,opened=in_use)
       enddo
       open(idist,file=hist_file(1:lent(hist_file)),
     .     status='old',iostat=ier)
       screen=nint(dist_par(1))
       if (ier.ne.0) then
```

```
   write(*,'(a)') '***** ERROR *****'
   write(*,'(a)') 'FDAS histogram file '//
 .    hist_file(1:lent(hist_file))//' could not be opened'
   stop
  else
   E=tensile(1)
   read(idist,'(a)') line
   write(iout,'(a)') '    MEASUREMENT:'//line(1:15)
   write(iout,'(a)') '    STRAIN GAGE:'//line(16:46)
   read(idist,'(a)') line
   read(idist,*) epsmax, epsmin, deps, dummy, tmin, tmax
   write(iout,'(a,f7.1,a)')
 .    '    MIN. STRAIN:',epsmin,' (uIN/IN)'
   write(iout,'(a,f7.1,a)')
 .    '    MAX. STRAIN:',epsmax,' (uIN/IN)'
   write(iout,'(a,2(f5.1,a),a)')
 .    '    START TIME: ',tmin,' sec   END TIME: ',tmax,' sec'
   epsmax=epsmax * .000001
   epsmin=epsmin * .000001
   if (deps.eq.0) then
     write(*,*) '***** ERROR reading histogram file *****'
     write(*,*)
 .   'Check for extra blank lines'
     stop
   end if
   deps=deps*.000001
   read(idist,*) fmin, fmax, ncol
   write(iout,'(2(a,f7.1),a,)')
 .    '   FREQUENCY RANGE: (',fmin,',',fmax,')'
   write(iout,'(a)')
   write(iout,'(a)') '    STRAIN RANGE HISTOGRAM'
   write(iout,'(a)')
   write(iout,'(a)') '       uIN/IN     # of occurrences'
   write(iout,'(a)')

  do i=1,80
   line(i:i)=' '
  enddo
  read(idist,'(a)') line
  nrec=nr(line)
  read(idist,*) (screen_list(ii),ii=1,nrec)
  icol=1
  do while ((screen_list(icol).ne.screen).and.(icol.le.nrec))
   icol=icol+1
  enddo
  no_data=(icol.gt.nrec)
```

```
        if (no_data) then
          write(iout,'(a)') '***** ERROR *****'
          write(iout,'(a,i3)')
     .     'No data for specified screening level ',screen
          write(iout,'(a,10i3)')
     .     'Available levels:',(screen_list(ii),ii=1,nrec)
          stop
        endif
        read(idist,'(a)') line
        npoint=1
        midbin_last=0.0d0
        read(idist,*,iostat=eof) (dummy,ii=1,icol)
        do while (eof.eq.0)
          midbin_cur=dummy
          if (midbin_cur.gt.0.0d0) write(iout,'(a,f12.7,i6)')
     .                 '    ',(npoint-0.5d0)*deps,midbin_cur
          hist(npoint)=(midbin_last+midbin_cur)/2.0d0
          midbin_last=midbin_cur
          nevents=nevents+midbin_cur
          npoint=npoint+1
          read(idist,*,iostat=eof) (dummy,ii=1,icol)
        enddo
        midbin_cur=0.0d0
        hist(npoint)=(midbin_last+midbin_cur)/2.0d0
        write(iout,'(a,i7)') '     The number of loops: ', nevents
        close(idist)
        s_alt_mn = 0
        s_alt_mx =(npoint-1)*deps*E
      endif
    endif
c
    return
    end
c
c--------|---------|---------|---------|---------|---------|---------|--
c
c               TEXT HANDLING ROUTINES:
c
c--------|---------|---------|---------|---------|---------|---------|--
c
    function lent(text)
c
c    return the real length of a string
c
    character text*(*)
    l=len(text)
```

```
      do 10 i=1,l
       j=l+1-i
       if (text(j:j).ne.' ') goto 20
   10 continue
   20 continue
      lent=j
      return
      end
c
      function nr(line)
c
c     number of records in a line, delimiter character must follow
c     record, blank records not recognized
c
      character*1 d
      character*80 line
c
      d=' '
      length=80
c
      n=0
      do i=1,length
       if ((line(i:i).ne.d).and.(line(i+1:i+1).eq.d)) n=n+1
      enddo
      nr=n
c
      return
      end
c
```

Appendix F
The CLS Influence Coefficient Database For Rockedyne and ATD Environments

Rockedyne Environment

```
0 1.04000E+00 0.00000E+00
  11
  33MCC-HGIR             0
 3.10000E-03 0.00000E+00 0.00000E+00 0.00000E+00
   2 3.10000E-03 7.75000E-05 0.00000E+00
  58HPFT-FLC             0
 1.01250E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.01250E+00 1.01250E-02 0.00000E+00
  19HPFT-EM              0
 1.03550E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.03550E+00 1.03550E-02 0.00000E+00
  59HPOT-FLC             0
 9.74086E-01 0.00000E+00 0.00000E+00 0.00000E+00
   2 9.74086E-01 9.74086E-03 0.00000E+00
  24HPOT-EM              0
 1.01523E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.01523E+00 1.01523E-02 0.00000E+00
  17HPFP-EM              0
 1.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.00000E+00 8.00000E-03 0.00000E+00
  12MCC-TH-D             0
 1.02930E+01 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.02930E+01 1.02930E-02 0.00000E+00
  1MR                    0
 6.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 6.00000E+00 1.20000E-02 0.00000E+00
  21HPOP-EM              0
 1.02000E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.02000E+00 4.08000E-03 0.00000E+00
   5O-TI                 0
 1.64000E+02 0.00000E+00 0.00000E+00 0.00000E+00
   3 1.64000E+02 1.31200E+00 0.00000E+00
  31HGM-O-R              0
 3.23800E-03 0.00000E+00 0.00000E+00 0.00000E+00
   2 3.23800E-03 1.61900E-04 0.00000E+00
   6
  59HPOT-PO
-1.62525E+02 3.74180E+03-5.84613E+02 3.23484E+02
 3.80038E-02 2.00491E-02 1.10335E-02 0.00000E+00
 3.80199E-02-3.67681E-03 1.77316E-02 0.00000E+00
```

4.73971E-02-1.90218E-01 9.53783E-02 0.00000E+00
1.55618E-02 3.24737E-02-7.58029E-03 0.00000E+00
-2.21598E-02 4.85034E-03-2.11556E-02 0.00000E+00
3.00414E-03-2.55482E-02-1.00390E-01 7.69522E-02
1.49546E-01-2.39050E-01 2.35872E-01 0.00000E+00
-2.31774E-02-2.26857E-02 0.00000E+00 0.00000E+00
-2.07868E-02 6.52575E-03-1.87423E-02 0.00000E+00
1.40076E-02-2.37627E-02 2.20115E-02 0.00000E+00
1.40244E-03 3.53627E-03 0.00000E+00 0.00000E+00
28HPOT-TO
5.27881E+02 7.14638E+02 1.10014E+02 0.00000E+00
8.76938E-02-1.38464E-01 8.59495E-02 0.00000E+00
5.49828E-01-4.93005E-01 6.33058E-01 0.00000E+00
3.12158E-01 5.62593E-01 0.00000E+00 0.00000E+00
9.41230E-01-1.95268E+00 6.88397E-01 0.00000E+00
-9.38390E-01-6.65554E-01 0.00000E+00 0.00000E+00
2.64995E-01 6.55636E-01 0.00000E+00 0.00000E+00
1.16789E+00 6.05180E+00 0.00000E+00 0.00000E+00
3.68985E+00-3.74619E+00 3.62700E+00 0.00000E+00
-8.52771E-01-5.82851E-01 0.00000E+00 0.00000E+00
1.33655E-01 5.23221E-01 0.00000E+00 0.00000E+00
-3.15027E-03 1.87352E-02 0.00000E+00 0.00000E+00
47HPOT-FL
-5.66738E+00 6.47847E+01-8.52202E+00 8.35196E+00
7.35996E-03 1.60583E-02 0.00000E+00 0.00000E+00
-3.79267E-03-2.77748E-01 1.21173E-01 0.00000E+00
1.69405E-01-8.84902E-01 4.73993E-01 0.00000E+00
3.68065E-01 4.08778E-01-1.54449E-01 0.00000E+00
-1.08070E-01 2.17806E-01-1.57267E-01 0.00000E+00
1.89274E-01-9.27625E-01 4.90244E-01 0.00000E+00
6.11653E-01-1.59343E+00 1.04701E+00 0.00000E+00
-6.80489E-01 0.00000E+00 0.00000E+00 0.00000E+00
-1.00889E-01 2.03471E-01-1.46217E-01 0.00000E+00
3.31667E-02-1.32205E-01 8.83281E-02 0.00000E+00
9.08068E-04-6.46334E-03 3.67413E-03 0.00000E+00
68O-TD-FLV
2.24662E+02 1.91227E+02 8.16731E+01-4.27524E+01
1.59480E-02-6.44156E-02 2.51366E-02 0.00000E+00
8.05301E-02 0.00000E+00 0.00000E+00 0.00000E+00
1.63269E-01 0.00000E+00 0.00000E+00 0.00000E+00
9.28326E-01-9.25001E-01 4.32525E-01 0.00000E+00
-4.74939E-01-7.33950E-01 4.34521E-01 0.00000E+00
1.50377E-01 0.00000E+00 0.00000E+00 0.00000E+00
2.03454E+00 8.90035E-01 0.00000E+00 0.00000E+00
8.74473E-01 0.00000E+00 0.00000E+00 0.00000E+00
-4.32195E-01-6.15437E-01 3.97544E-01 0.00000E+00

1.85473E-01 6.72725E-02 0.00000E+00 0.00000E+00
-1.54616E-04 0.00000E+00 0.00000E+00 0.00000E+00
67O-TD-DP
-3.52017E-01 6.39715E+00 9.29429E+00 1.26336E+00
2.03314E-02-4.12703E-02 2.09770E-02 0.00000E+00
2.11092E-01-6.02431E-01 3.10627E-01 0.00000E+00
6.40785E-01-1.59253E+00 8.66676E-01 0.00000E+00
1.31075E+00-5.49696E-01 2.92799E-01 0.00000E+00
-5.78645E-01-5.30439E-01 2.86327E-01 0.00000E+00
6.50437E-01-1.63950E+00 8.86311E-01 0.00000E+00
1.88770E+00 1.12798E+00 0.00000E+00 0.00000E+00
1.89765E-01 0.00000E+00 0.00000E+00 0.00000E+00
-5.29506E-01-4.24329E-01 2.58913E-01 0.00000E+00
1.55111E-01 8.96149E-02 0.00000E+00 0.00000E+00
-1.98267E-03 0.00000E+00 0.00000E+00 0.00000E+00
71HPOT-MR
5.79999E-02 6.74253E-01 0.00000E+00 0.00000E+00
1.32296E-01-2.29873E-01 1.32960E-01 0.00000E+00
8.59715E-01-8.51682E-01 8.75556E-01 0.00000E+00
5.58767E-01 5.85897E-01 0.00000E+00 0.00000E+00
1.23401E+00-2.67393E+00 9.64603E-01 0.00000E+00
-1.02553E+00-1.44860E+00 5.08712E-01 0.00000E+00
5.52995E-01 7.18747E-01 0.00000E+00 0.00000E+00
2.60284E+00 6.87316E+00 0.00000E+00 0.00000E+00
5.21572E+00-5.72693E+00 4.99998E+00 0.00000E+00
-9.61487E-01-1.36544E+00 4.69507E-01 0.00000E+00
2.61583E-01 5.96607E-01 0.00000E+00 0.00000E+00
2.10220E-02-2.83551E-02 2.61451E-02 0.00000E+00
2
14
14945OXTDLCF
0 0.10000E+01 0.50000E-01 0.00000E+00
14
14995OxTDDen
0 0.00000E+00 0.00000E+00 0.00000E+00

ATD Environment

0 1.04000E+00 0.00000E+00
9
33MCC-HGIR 0
1.88000E-03 0.00000E+00 0.00000E+00 0.00000E+00
2 1.88000E-03 4.70000E-05 0.00000E+00
31HGM-O-R 0
4.21300E-03 0.00000E+00 0.00000E+00 0.00000E+00
2 4.21300E-03 2.10650E-04 0.00000E+00

```
  19HPFT-EM            0
 1.53059E+00-1.23249E+00 6.96662E-01 0.00000E+00
   2 9.94762E-01 9.94762E-03 0.00000E+00
  24HPOT-EM            0
 1.01134E+00-1.35688E-01 8.48348E-02 0.00000E+00
   2 9.60487E-01 9.60487E-03 0.00000E+00
  12MCC-TH-D           0
 1.02897E+01 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.02897E+01 1.02897E-02 0.00000E+00
   1MR                 0
 6.01100E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 6.01100E+00 1.20220E-02 0.00000E+00
  17HPFP-EM            0
 1.01420E+00 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.01420E+00 8.11360E-03 0.00000E+00
  21HPOP-EM            0
 9.44580E-01 0.00000E+00 0.00000E+00 0.00000E+00
   2 9.44580E-01 3.77832E-03 0.00000E+00
  5O-TI                0
 1.64000E+02 0.00000E+00 0.00000E+00 0.00000E+00
   2 1.64000E+02 1.31200E+00 0.00000E+00
  6
  59HPOT-PO
-1.28141E+02 3.55910E+03-4.78801E+02 2.67160E+02
-6.42784E-03 8.39461E-02-3.04386E-02 0.00000E+00
 2.45140E-03 6.17029E-03 0.00000E+00 0.00000E+00
 1.92183E-02-9.38550E-02 4.44679E-02 0.00000E+00
 6.64246E-03-5.22452E-02 1.81303E-02 0.00000E+00
 9.06399E-03 6.28164E-02 5.15322E-02 0.00000E+00
 1.15774E-02-7.31043E-02 3.81217E-02 0.00000E+00
 2.24843E-02-1.02349E-01 5.01142E-02 0.00000E+00
 5.47921E-03-4.56015E-02 1.48806E-02 0.00000E+00
-2.42907E-03 1.33203E-02 0.00000E+00 0.00000E+00
  28HPOT-TO
 4.75369E+02 8.94899E+02 0.00000E+00 0.00000E+00
 3.38511E-02-4.32422E-02 3.58584E-02 0.00000E+00
 6.73452E-03 2.03458E-02 0.00000E+00 0.00000E+00
 3.76597E-01 4.27971E-01 0.00000E+00 0.00000E+00
-9.47366E-01-3.69901E-01 0.00000E+00 0.00000E+00
 2.22431E+00 2.91563E+00 1.63280E+00 0.00000E+00
 3.65318E+00-3.67520E+00 3.31786E+00 0.00000E+00
 3.31726E-01 4.97135E-01 0.00000E+00 0.00000E+00
-8.30857E-01-4.10014E-01 0.00000E+00 0.00000E+00
 1.92919E-01 3.90407E-01 0.00000E+00 0.00000E+00
  47HPOT-FL
-1.00559E+00 5.02082E+01 1.46246E+01 0.00000E+00
```

```
-1.60801E-03 2.61602E-02-9.37004E-03 0.00000E+00
 2.96659E-04-7.22774E-03 4.39088E-03 0.00000E+00
-8.45317E-02-2.76528E-01 1.67250E-01 0.00000E+00
-2.23498E-02-2.10906E-01 1.10354E-01 0.00000E+00
 2.89712E-01-1.81360E-01 4.30025E-01 0.00000E+00
-5.95994E-01 8.29507E-02 0.00000E+00 0.00000E+00
-5.62653E-02-3.32458E-01 1.94293E-01 0.00000E+00
-2.91796E-02-1.73173E-01 8.20772E-02 0.00000E+00
 2.10456E-02-4.76237E-02 6.55236E-02 0.00000E+00
  68O-TD-FLV
 2.17170E+02 3.83897E+02-5.54395E+01 0.00000E+00
 1.87688E-02-6.26564E-02 2.86364E-02 0.00000E+00
 1.85518E-03 0.00000E+00 0.00000E+00 0.00000E+00
 1.73666E-01 0.00000E+00 0.00000E+00 0.00000E+00
-5.71601E-01-5.13018E-01 3.49305E-01 0.00000E+00
 1.97388E+00 1.17756E+00 0.00000E+00 0.00000E+00
 1.40821E+00-1.29232E+00 8.38458E-01 0.00000E+00
 1.59397E-01 0.00000E+00 0.00000E+00 0.00000E+00
-5.20224E-01-4.40806E-01 3.03036E-01 0.00000E+00
 1.88933E-01 9.57015E-02 0.00000E+00 0.00000E+00
  67O-TD-DP
 9.28812E+00-2.72378E+01 5.52318E+01-1.47986E+01
 5.02196E-04 0.00000E+00 0.00000E+00 0.00000E+00
-6.84025E-04 0.00000E+00 0.00000E+00 0.00000E+00
-2.21956E-02 0.00000E+00 0.00000E+00 0.00000E+00
-5.92775E-01-7.09955E-01 4.49178E-01 0.00000E+00
 1.93179E+00 1.80076E+00 0.00000E+00 0.00000E+00
 8.05613E-01-1.22990E+00 8.53059E-01 0.00000E+00
-3.38411E-02 0.00000E+00 0.00000E+00 0.00000E+00
-5.47858E-01-6.03419E-01 3.76953E-01 0.00000E+00
 1.63600E-01 1.61550E-01 0.00000E+00 0.00000E+00
  71HPOT-MR
 6.49026E-02 6.28848E-01 0.00000E+00 0.00000E+00
 2.73289E-02 0.00000E+00 0.00000E+00 0.00000E+00
 1.35013E-02 2.03251E-02 0.00000E+00 0.00000E+00
 6.65398E-01 3.81740E-01 0.00000E+00 0.00000E+00
-1.43466E+00-1.81700E-01 0.00000E+00 0.00000E+00
 4.75146E+00 1.08530E+00 3.13556E+00 0.00000E+00
 5.03273E+00-5.34341E+00 4.43063E+00 0.00000E+00
 6.70812E-01 4.79229E-01 0.00000E+00 0.00000E+00
-1.30538E+00-3.06626E-01 0.00000E+00 0.00000E+00
 3.56534E-01 3.99690E-01 0.00000E+00 0.00000E+00
  2
  14
14945OXTDLCF
  0 0.10000E+01 0.50000E-01 0.00000E+00
```

14
14995OxTDDen
0 0.00000E+00 0.00000E+00 0.00000E+00

Appendix G
NESSUS/FEM Input Deck for Redesign Case

```
*FEM
C HEX TURAROUND VANE
*DISP
*BOUNDARY    24
*CONSTITUTIVE   0
*DUPLICATENODES  84
*ELEMENTS        740
  75
*FORCE 792
*FREQUENCYBANDS 4 3  0  1
*MODAL  50 100
 50
*NODES  942
*OPTIMIZE  1
*POST
*PRINT
*MONITOR 1
C 11 by 6  nodes per two vanes * 6 DOF
C number of excitation points is (11*6 )*2*6 = 792
*PSD  2  792   495
*COEF 10
*END
*COEF
 1  1.88E-03
 2  4.213E-3
 3  1.01488
 4  0.960487
 5  1.02897E+01
 6  1.0142
 7  0.94458
 8  0.72
 9  0.0
10  0.0
C
*COORDINATES
C
C *****************************************************
C *                QUAD-MODEL                *
C *****************************************************
C
   1    0.00000000    5.54800000    4.80730000   0.15100
   2    0.21440000    5.49510000    4.76150000   0.15100
   3    0.41910000    5.42400000    4.69990000   0.15100
```

4	0.61170000	5.33640000	4.62400000	0.15100
5	0.78950000	5.23210000	4.53360000	0.15100
6	0.95030000	5.11270000	4.43010000	0.15100
7	0.00000000	5.40840000	4.96380000	0.11100
8	0.21440000	5.35680000	4.91640000	0.11100
9	0.41910000	5.28760000	4.85290000	0.11100
10	0.61170000	5.20210000	4.77440000	0.11100
11	0.78950000	5.10050000	4.68120000	0.11100
12	0.95030000	4.98400000	4.57430000	0.11100
13	0.00000000	5.26450000	5.11620000	0.07000
14	0.21440000	5.21420000	5.06740000	0.07000
15	0.41910000	5.14690000	5.00190000	0.07000
16	0.61170000	5.06370000	4.92110000	0.07000
17	0.78950000	4.96470000	4.82490000	0.07000
18	0.95030000	4.85140000	4.71480000	0.07000
19	0.00000000	5.11620000	5.26450000	0.07000
20	0.21440000	5.06740000	5.21420000	0.07000
21	0.41910000	5.00200000	5.14690000	0.07000
22	0.61170000	4.92110000	5.06370000	0.07000
23	0.78950000	4.82490000	4.96470000	0.07000
24	0.95030000	4.71480000	4.85140000	0.07000
25	0.00000000	4.96380000	5.40840000	0.07000
26	0.21440000	4.91650000	5.35680000	0.07000
27	0.41910000	4.85290000	5.28760000	0.07000
28	0.61170000	4.77450000	5.20210000	0.07000
29	0.78950000	4.68120000	5.10050000	0.07000
30	0.95030000	4.57430000	4.98400000	0.07000
31	0.00000000	4.80740000	5.54790000	0.07000
32	0.21440000	4.76150000	5.49510000	0.07000
33	0.41910000	4.69990000	5.42400000	0.07000
34	0.61170000	4.62390000	5.33630000	0.07000
35	0.78950000	4.53360000	5.23200000	0.07000
36	0.95030000	4.43010000	5.11260000	0.07000
37	0.00000000	4.64700000	5.68300000	0.07000
38	0.21440000	4.60260000	5.62880000	0.07000
39	0.41910000	4.54320000	5.55600000	0.07000
40	0.61170000	4.46970000	5.46630000	0.07000
41	0.78950000	4.38240000	5.35940000	0.07000
42	0.95030000	4.28230000	5.23710000	0.07000
43	0.00000000	4.48280000	5.81340000	0.07000
44	0.21440000	4.44000000	5.75800000	0.07000
45	0.41910000	4.38270000	5.68350000	0.07000
46	0.61170000	4.31190000	5.59160000	0.07000
47	0.78950000	4.22750000	5.48230000	0.07000
48	0.95030000	4.13100000	5.35730000	0.07000
49	0.00000000	4.31490000	5.93900000	0.07000

50	0.21440000	4.27370000	5.88240000	0.07000
51	0.41910000	4.21850000	5.80630000	0.07000
52	0.61170000	4.15040000	5.71250000	0.07000
53	0.78950000	4.06930000	5.60080000	0.07000
54	0.95030000	3.97640000	5.47300000	0.07000
55	0.00000000	4.14360000	6.05980000	0.11100
56	0.21440000	4.10410000	6.00200000	0.11100
57	0.41910000	4.05100000	5.92440000	0.11100
58	0.61170000	3.98550000	5.82860000	0.11100
59	0.78950000	3.90770000	5.71480000	0.11100
60	0.95030000	3.81840000	5.58430000	0.11100
61	0.00000000	3.96880000	6.17560000	0.15100
62	0.21440000	3.93100000	6.11680000	0.15100
63	0.41910000	3.88020000	6.03770000	0.15100
64	0.61170000	3.81750000	5.94010000	0.15100
65	0.78950000	3.74290000	5.82400000	0.15100
66	0.95030000	3.65750000	5.69110000	0.15100
67	0.00000000	3.79090000	6.28650000	0.11100
68	0.21440000	3.75470000	6.22650000	0.11100
69	0.41910000	3.70620000	6.14600000	0.11100
70	0.61170000	3.64630000	6.04670000	0.11100
71	0.78950000	3.57510000	5.92850000	0.11100
72	0.95030000	3.49340000	5.79320000	0.11100
73	0.00000000	3.60990000	6.39210000	0.07000
74	0.21440000	3.57540000	6.33120000	0.07000
75	0.41910000	3.52920000	6.24930000	0.07000
76	0.61170000	3.47220000	6.14830000	0.07000
77	0.78950000	3.40430000	6.02820000	0.07000
78	0.95030000	3.32660000	5.89060000	0.07000
79	0.00000000	3.42580000	6.49260000	0.07000
80	0.21440000	3.39310000	6.43070000	0.07000
81	0.41910000	3.34930000	6.34760000	0.07000
82	0.61170000	3.29510000	6.24500000	0.07000
83	0.78950000	3.23080000	6.12290000	0.07000
84	0.95030000	3.15700000	5.98320000	0.07000
85	0.00000000	3.23910000	6.58780000	0.07000
86	0.21440000	3.20810000	6.52500000	0.07000
87	0.41910000	3.16660000	6.44060000	0.07000
88	0.61170000	3.11550000	6.33650000	0.07000
89	0.78950000	3.05460000	6.21260000	0.07000
90	0.95030000	2.98490000	6.07090000	0.07000
91	0.00000000	3.04950000	6.67760000	0.07000
92	0.21440000	3.02050000	6.61390000	0.07000
93	0.41910000	2.98140000	6.52840000	0.07000
94	0.61170000	2.93330000	6.42290000	0.07000
95	0.78950000	2.87600000	6.29740000	0.07000

96	0.95030000	2.81030000	6.15370000	0.07000
97	0.00000000	2.85760000	6.76200000	0.07000
98	0.21440000	2.83040000	6.69750000	0.07000
99	0.41910000	2.79380000	6.61080000	0.07000
100	0.61170000	2.74860000	6.50410000	0.07000
101	0.78950000	2.69490000	6.37700000	0.07000
102	0.95030000	2.63340000	6.23140000	0.07000
103	0.00000000	2.66340000	6.84080000	0.07000
104	0.21440000	2.63800000	6.77550000	0.07000
105	0.41910000	2.60390000	6.68800000	0.07000
106	0.61170000	2.56180000	6.57990000	0.07000
107	0.78950000	2.51170000	6.45120000	0.07000
108	0.95030000	2.45440000	6.30410000	0.07000
109	0.00000000	2.46690000	6.91400000	0.07000
110	0.21440000	2.44340000	6.84820000	0.07000
111	0.41910000	2.41180000	6.75960000	0.07000
112	0.61170000	2.37280000	6.65030000	0.07000
113	0.78950000	2.32650000	6.52040000	0.07000
114	0.95030000	2.27340000	6.37160000	0.07000
115	0.00000000	2.26850000	6.98170000	0.11100
116	0.21440000	2.24690000	6.91510000	0.11100
117	0.41910000	2.21780000	6.82570000	0.11100
118	0.61170000	2.18200000	6.71540000	0.11100
119	0.78950000	2.13930000	6.58410000	0.11100
120	0.95030000	2.09050000	6.43390000	0.11100
121	0.00000000	2.06820000	7.04360000	0.15100
122	0.21440000	2.04850000	6.97650000	0.15100
123	0.41910000	2.02200000	6.88630000	0.15100
124	0.61170000	1.98930000	6.77500000	0.15100
125	0.78950000	1.95040000	6.64260000	0.15100
126	0.95030000	1.90600000	6.49100000	0.15100
127	0.00000000	1.86620000	7.09980000	0.11100
128	0.21440000	1.84840000	7.03210000	0.11100
129	0.41910000	1.82450000	6.94120000	0.11100
130	0.61170000	1.79510000	6.82900000	0.11100
131	0.78950000	1.76000000	6.69550000	0.11100
132	0.95030000	1.71980000	6.54280000	0.11100
133	0.00000000	1.66270000	7.15020000	0.07000
134	0.21440000	1.64690000	7.08210000	0.07000
135	0.41910000	1.62560000	6.99040000	0.07000
136	0.61170000	1.59930000	6.87760000	0.07000
137	0.78950000	1.56810000	6.74300000	0.07000
138	0.95030000	1.53220000	6.58920000	0.07000
139	0.00000000	1.45790000	7.19480000	0.07000
140	0.21440000	1.44400000	7.12610000	0.07000
141	0.41910000	1.42530000	7.03400000	0.07000

142	0.61170000	1.40220000	6.92040000	0.07000
143	0.78950000	1.37480000	6.78510000	0.07000
144	0.95030000	1.34350000	6.63020000	0.07000
145	0.00000000	1.25190000	7.23350000	0.07000
146	0.21440000	1.23990000	7.16450000	0.07000
147	0.41910000	1.22390000	7.07180000	0.07000
148	0.61170000	1.20410000	6.95760000	0.07000
149	0.78950000	1.18060000	6.82160000	0.07000
150	0.95030000	1.15360000	6.66590000	0.07000
151	0.00000000	1.04480000	7.26630000	0.07000
152	0.21440000	1.03480000	7.19700000	0.07000
153	0.41910000	1.02140000	7.10390000	0.07000
154	0.61170000	1.00480000	6.98910000	0.07000
155	0.78950000	0.98529000	6.85260000	0.07000
156	0.95030000	0.96276000	6.69610000	0.07000
157	0.00000000	0.83681000	7.29310000	0.07000
158	0.21440000	0.82879000	7.22360000	0.07000
159	0.41910000	0.81814000	7.13020000	0.07000
160	0.61170000	0.80486000	7.01500000	0.07000
161	0.78950000	0.78918000	6.87790000	0.07000
162	0.95030000	0.77121000	6.72090000	0.07000
163	0.00000000	0.62826000	7.31410000	0.07000
164	0.21440000	0.62228000	7.24430000	0.07000
165	0.41910000	0.61423000	7.15070000	0.07000
166	0.61170000	0.60427000	7.03510000	0.07000
167	0.78950000	0.59244000	6.89760000	0.07000
168	0.95030000	0.57892000	6.74020000	0.07000
169	0.00000000	0.41906000	7.32900000	0.07000
170	0.21440000	0.41506000	7.25910000	0.07000
171	0.41910000	0.40969000	7.16530000	0.07000
172	0.61170000	0.40311000	7.04950000	0.07000
173	0.78950000	0.39524000	6.91170000	0.07000
174	0.95030000	0.38623000	6.75400000	0.07000
175	0.00000000	0.20965000	7.33800000	0.11100
176	0.21440000	0.20770000	7.26800000	0.11100
177	0.41910000	0.20495000	7.17410000	0.11100
178	0.61170000	0.20169000	7.05810000	0.11100
179	0.78950000	0.19771000	6.92020000	0.11100
180	0.95030000	0.19314000	6.76230000	0.11100
181	0.00000000	-0.00004067	7.34100000	0.15100
182	0.21440000	-0.00001236	7.27100000	0.15100
183	0.41910000	-0.00000560	7.17700000	0.15100
184	0.61170000	0.00006397	7.06100000	0.15100
185	0.78950000	-0.00001954	6.92300000	0.15100
186	0.95030000	0.00001577	6.76490000	0.15100
187	0.00000000	-0.20967000	7.33800000	0.11100

188	0.21440000	-0.20766000	7.26800000	0.11100
189	0.41910000	-0.20495000	7.17400000	0.11100
190	0.61170000	-0.20161000	7.05810000	0.11100
191	0.78950000	-0.19773000	6.92020000	0.11100
192	0.95030000	-0.19321000	6.76220000	0.11100
193	0.00000000	-0.41908000	7.32910000	0.07000
194	0.21440000	-0.41508000	7.25910000	0.07000
195	0.41910000	-0.40974000	7.16530000	0.07000
196	0.61170000	-0.40307000	7.04950000	0.07000
197	0.78950000	-0.39520000	6.91170000	0.07000
198	0.95030000	-0.38621000	6.75390000	0.07000
199	0.00000000	-0.62822000	7.31410000	0.07000
200	0.21440000	-0.62222000	7.24440000	0.07000
201	0.41910000	-0.61418000	7.15060000	0.07000
202	0.61170000	-0.60422000	7.03520000	0.07000
203	0.78950000	-0.59244000	6.89760000	0.07000
204	0.95030000	-0.57888000	6.74020000	0.07000
205	0.00000000	-0.83679000	7.29320000	0.07000
206	0.21440000	-0.82879000	7.22360000	0.07000
207	0.41910000	-0.81810000	7.13020000	0.07000
208	0.61170000	-0.80494000	7.01500000	0.07000
209	0.78950000	-0.78916000	6.87780000	0.07000
210	0.95030000	-0.77110000	6.72090000	0.07000
211	0.00000000	-1.04470000	7.26620000	0.07000
212	0.21440000	-1.03480000	7.19700000	0.07000
213	0.41910000	-1.02140000	7.10400000	0.07000
214	0.61170000	-1.00490000	6.98920000	0.07000
215	0.78950000	-0.98520000	6.85260000	0.07000
216	0.95030000	-0.96279000	6.69610000	0.07000
217	0.00000000	-1.25180000	7.23350000	0.07000
218	0.21440000	-1.23990000	7.16450000	0.07000
219	0.41910000	-1.22380000	7.07190000	0.07000
220	0.61170000	-1.20400000	6.95760000	0.07000
221	0.78950000	-1.18050000	6.82160000	0.07000
222	0.95030000	-1.15360000	6.66590000	0.07000
223	0.00000000	-1.45780000	7.19470000	0.07000
224	0.21440000	-1.44390000	7.12620000	0.07000
225	0.41910000	-1.42520000	7.03400000	0.07000
226	0.61170000	-1.40220000	6.92030000	0.07000
227	0.78950000	-1.37480000	6.78520000	0.07000
228	0.95030000	-1.34340000	6.63030000	0.07000
229	0.00000000	-1.66270000	7.15020000	0.07000
230	0.21440000	-1.64690000	7.08200000	0.07000
231	0.41910000	-1.62560000	6.99050000	0.07000
232	0.61170000	-1.59930000	6.87750000	0.07000
233	0.78950000	-1.56800000	6.74300000	0.07000

234	0.95030000	-1.53230000	6.58920000	0.07000
235	0.00000000	-1.86620000	7.09980000	0.11100
236	0.21440000	-1.84840000	7.03210000	0.11100
237	0.41910000	-1.82450000	6.94120000	0.11100
238	0.61170000	-1.79500000	6.82900000	0.11100
239	0.78950000	-1.75990000	6.69560000	0.11100
240	0.95030000	-1.71970000	6.54280000	0.11100
241	0.00000000	-2.06820000	7.04370000	0.15100
242	0.21440000	-2.04840000	6.97650000	0.15100
243	0.41910000	-2.02200000	6.88620000	0.15100
244	0.61170000	-1.98930000	6.77490000	0.15100
245	0.78950000	-1.95040000	6.64260000	0.15100
246	0.95030000	-1.90590000	6.49100000	0.15100
247	0.00000000	-2.26850000	6.98170000	0.11100
248	0.21440000	-2.24680000	6.91520000	0.11100
249	0.41910000	-2.21780000	6.82570000	0.11100
250	0.61170000	-2.18200000	6.71540000	0.11100
251	0.78950000	-2.13930000	6.58410000	0.11100
252	0.95030000	-2.09050000	6.43390000	0.11100
253	0.00000000	-2.46690000	6.91410000	0.07000
254	0.21440000	-2.44340000	6.84820000	0.07000
255	0.41910000	-2.41180000	6.75960000	0.07000
256	0.61170000	-2.37280000	6.65040000	0.07000
257	0.78950000	-2.32650000	6.52040000	0.07000
258	0.95030000	-2.27340000	6.37160000	0.07000
259	0.00000000	-2.66340000	6.84080000	0.07000
260	0.21440000	-2.63800000	6.77560000	0.07000
261	0.41910000	-2.60390000	6.68800000	0.07000
262	0.61170000	-2.56180000	6.57990000	0.07000
263	0.78950000	-2.51170000	6.45130000	0.07000
264	0.95030000	-2.45440000	6.30410000	0.07000
265	0.00000000	-2.85760000	6.76200000	0.07000
266	0.21440000	-2.83030000	6.69750000	0.07000
267	0.41910000	-2.79380000	6.61090000	0.07000
268	0.61170000	-2.74860000	6.50410000	0.07000
269	0.78950000	-2.69490000	6.37700000	0.07000
270	0.95030000	-2.63340000	6.23140000	0.07000
271	0.00000000	-3.04950000	6.67760000	0.07000
272	0.21440000	-3.02050000	6.61400000	0.07000
273	0.41910000	-2.98140000	6.52850000	0.07000
274	0.61170000	-2.93330000	6.42290000	0.07000
275	0.78950000	-2.87600000	6.29740000	0.07000
276	0.95030000	-2.81030000	6.15370000	0.07000
277	0.00000000	-3.23900000	6.58780000	0.07000
278	0.21440000	-3.20810000	6.52500000	0.07000
279	0.41910000	-3.16660000	6.44060000	0.07000

280	0.61170000	-3.11550000	6.33650000	0.07000
281	0.78950000	-3.05460000	6.21280000	0.07000
282	0.95030000	-2.98480000	6.07090000	0.07000
283	0.00000000	-3.42580000	6.49260000	0.07000
284	0.21440000	-3.39310000	6.43070000	0.07000
285	0.41910000	-3.34920000	6.34760000	0.07000
286	0.61170000	-3.29510000	6.24500000	0.07000
287	0.78950000	-3.23080000	6.12290000	0.07000
288	0.95030000	-3.15700000	5.98320000	0.07000
289	0.00000000	-3.60980000	6.39220000	0.07000
290	0.21440000	-3.57540000	6.33120000	0.07000
291	0.41910000	-3.52920000	6.24940000	0.07000
292	0.61170000	-3.47220000	6.14830000	0.07000
293	0.78950000	-3.40430000	6.02810000	0.07000
294	0.95030000	-3.32660000	5.89070000	0.07000
295	0.00000000	-3.79090000	6.28650000	0.11100
296	0.21440000	-3.75470000	6.22650000	0.11100
297	0.41910000	-3.70620000	6.14600000	0.11100
298	0.61170000	-3.64630000	6.04670000	0.11100
299	0.78950000	-3.57500000	5.92850000	0.11100
300	0.95030000	-3.49340000	5.79320000	0.11100
301	0.00000000	-3.96890000	6.17560000	0.15100
302	0.21440000	-3.93100000	6.11680000	0.15100
303	0.41910000	-3.88010000	6.03770000	0.15100
304	0.61170000	-3.81740000	5.94010000	0.15100
305	0.78950000	-3.74280000	5.82400000	0.15100
306	0.95030000	-3.65740000	5.69110000	0.15100
307	0.00000000	-4.14350000	6.05980000	0.11100
308	0.21440000	-4.10410000	6.00200000	0.11100
309	0.41910000	-4.05100000	5.92440000	0.11100
310	0.61170000	-3.98550000	5.82870000	0.11100
311	0.78950000	-3.90770000	5.71480000	0.11100
312	0.95030000	-3.81840000	5.58430000	0.11100
313	0.00000000	-4.31490000	5.93900000	0.07000
314	0.21440000	-4.27380000	5.88240000	0.07000
315	0.41910000	-4.21850000	5.80630000	0.07000
316	0.61170000	-4.15030000	5.71250000	0.07000
317	0.78950000	-4.06920000	5.60080000	0.07000
318	0.95030000	-3.97640000	5.47300000	0.07000
319	0.00000000	-4.48270000	5.81330000	0.07000
320	0.21440000	-4.44000000	5.75790000	0.07000
321	0.41910000	-4.38260000	5.68350000	0.07000
322	0.61170000	-4.31180000	5.59160000	0.07000
323	0.78950000	-4.22750000	5.48230000	0.07000
324	0.95030000	-4.13100000	5.35730000	0.07000
325	0.00000000	-4.64690000	5.68300000	0.07000

326	0.21440000	-4.60260000	5.62880000	0.07000
327	0.41910000	-4.54310000	5.55600000	0.07000
328	0.61170000	-4.46970000	5.46620000	0.07000
329	0.78950000	-4.38240000	5.35940000	0.07000
330	0.95030000	-4.28230000	5.23700000	0.07000
331	0.00000000	-4.80730000	5.54800000	0.07000
332	0.21440000	-4.76150000	5.49510000	0.07000
333	0.41910000	-4.69990000	5.42400000	0.07000
334	0.61170000	-4.62400000	5.33640000	0.07000
335	0.78950000	-4.53360000	5.23210000	0.07000
336	0.95030000	-4.43010000	5.11270000	0.07000
337	0.00000000	-4.96380000	5.40840000	0.07000
338	0.21440000	-4.91640000	5.35680000	0.07000
339	0.41910000	-4.85290000	5.28760000	0.07000
340	0.61170000	-4.77440000	5.20210000	0.07000
341	0.78950000	-4.68120000	5.10050000	0.07000
342	0.95030000	-4.57430000	4.98400000	0.07000
343	0.00000000	-5.11620000	5.26450000	0.07000
344	0.21440000	-5.06740000	5.21420000	0.07000
345	0.41910000	-5.00190000	5.14690000	0.07000
346	0.61170000	-4.92110000	5.06370000	0.07000
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350	0.21440000	-5.21420000	5.06740000	0.07000
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354	0.95030000	-4.85140000	4.71480000	0.07000
355	0.00000000	-5.40840000	4.96380000	0.11100
356	0.21440000	-5.35680000	4.91650000	0.11100
357	0.41910000	-5.28760000	4.85290000	0.11100
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361	0.00000000	-5.54790000	4.80740000	0.15100
362	0.21440000	-5.49510000	4.76150000	0.15100
363	0.41910000	-5.42400000	4.69990000	0.15100
364	0.61170000	-5.33630000	4.62390000	0.15100
365	0.78950000	-5.23200000	4.53360000	0.15100
366	0.95030000	-5.11260000	4.43010000	0.15100
367	0.00000000	6.03920000	5.23300000	0.15100
368	0.33230000	5.90920000	5.12030000	0.15100
369	0.64010000	5.74900000	4.98150000	0.15100
370	0.91850000	5.56080000	4.81850000	0.15100
371	1.16300000	5.34770000	4.63380000	0.15100

372	1.37000000	5.11270000	4.43010000	0.15100
373	0.00000000	5.88730000	5.40330000	0.11100
374	0.33230000	5.76060000	5.28700000	0.11100
375	0.64010000	5.60440000	5.14370000	0.11100
376	0.91850000	5.42090000	4.97530000	0.11100
377	1.16300000	5.21320000	4.78460000	0.11100
378	1.37000000	4.98400000	4.57430000	0.11100
379	0.00000000	5.73060000	5.56920000	0.07000
380	0.33230000	5.60720000	5.44930000	0.07000
381	0.64010000	5.45520000	5.30160000	0.07000
382	0.91850000	5.27670000	5.12810000	0.07000
383	1.16300000	5.07450000	4.93150000	0.07000
384	1.37000000	4.85140000	4.71480000	0.07000
385	0.00000000	5.56920000	5.73060000	0.07000
386	0.33230000	5.44940000	5.60720000	0.07000
387	0.64010000	5.30160000	5.45520000	0.07000
388	0.91850000	5.12810000	5.27660000	0.07000
389	1.16300000	4.93150000	5.07440000	0.07000
390	1.37000000	4.71480000	4.85140000	0.07000
391	0.00000000	5.40330000	5.88730000	0.07000
392	0.33230000	5.28700000	5.76050000	0.07000
393	0.64010000	5.14370000	5.60440000	0.07000
394	0.91850000	4.97530000	5.42090000	0.07000
395	1.16300000	4.78460000	5.21320000	0.07000
396	1.37000000	4.57430000	4.98400000	0.07000
397	0.00000000	5.23310000	6.03920000	0.07000
398	0.33230000	5.12030000	5.90920000	0.07000
399	0.64010000	4.98150000	5.74900000	0.07000
400	0.91850000	4.81840000	5.56080000	0.07000
401	1.16300000	4.63380000	5.34770000	0.07000
402	1.37000000	4.43010000	5.11260000	0.07000
403	0.00000000	5.05850000	6.18610000	0.07000
404	0.33230000	4.94960000	6.05300000	0.07000
405	0.64010000	4.81530000	5.88890000	0.07000
406	0.91850000	4.65770000	5.69610000	0.07000
407	1.16300000	4.47920000	5.47780000	0.07000
408	1.37000000	4.28230000	5.23710000	0.07000
409	0.00000000	4.87970000	6.32800000	0.07000
410	0.33230000	4.77470000	6.19190000	0.07000
411	0.64010000	4.64520000	6.02400000	0.07000
412	0.91850000	4.49310000	5.82680000	0.07000
413	1.16300000	4.32100000	5.60350000	0.07000
414	1.37000000	4.13100000	5.35730000	0.07000
415	0.00000000	4.69700000	6.46480000	0.07000
416	0.33230000	4.59590000	6.32570000	0.07000
417	0.64010000	4.47130000	6.15420000	0.07000

418	0.91850000	4.32490000	5.95280000	0.07000
419	1.16300000	4.15920000	5.72460000	0.07000
420	1.37000000	3.97640000	5.47300000	0.07000
421	0.00000000	4.51050000	6.59640000	0.11100
422	0.33230000	4.41340000	6.45430000	0.11100
423	0.64010000	4.29380000	6.27930000	0.11100
424	0.91850000	4.15320000	6.07380000	0.11100
425	1.16300000	3.99400000	5.84100000	0.11100
426	1.37000000	3.81840000	5.58430000	0.11100
427	0.00000000	4.32030000	6.72240000	0.15100
428	0.33230000	4.22730000	6.57780000	0.15100
429	0.64010000	4.11270000	6.39940000	0.15100
430	0.91850000	3.97800000	6.18990000	0.15100
431	1.16300000	3.82560000	5.95270000	0.15100
432	1.37000000	3.65750000	5.69110000	0.15100
433	0.00000000	4.12650000	6.84310000	0.11100
434	0.33230000	4.03770000	6.69580000	0.11100
435	0.64010000	3.92830000	6.51430000	0.11100
436	0.91850000	3.79970000	6.30100000	0.11100
437	1.16300000	3.65410000	6.05950000	0.11100
438	1.37000000	3.49340000	5.79320000	0.11100
439	0.00000000	3.92940000	6.95820000	0.07000
440	0.33230000	3.84490000	6.80840000	0.07000
441	0.64010000	3.74060000	6.62370000	0.07000
442	0.91850000	3.61820000	6.40700000	0.07000
443	1.16300000	3.47950000	6.16140000	0.07000
444	1.37000000	3.32660000	5.89060000	0.07000
445	0.00000000	3.72910000	7.06750000	0.07000
446	0.33230000	3.64880000	6.91540000	0.07000
447	0.64010000	3.54990000	6.72790000	0.07000
448	0.91850000	3.43380000	6.50770000	0.07000
449	1.16300000	3.30220000	6.25820000	0.07000
450	1.37000000	3.15700000	5.98320000	0.07000
451	0.00000000	3.52580000	7.17110000	0.07000
452	0.33230000	3.44990000	7.01680000	0.07000
453	0.64010000	3.35640000	6.82650000	0.07000
454	0.91850000	3.24650000	6.60300000	0.07000
455	1.16300000	3.12210000	6.35000000	0.07000
456	1.37000000	2.98490000	6.07090000	0.07000
457	0.00000000	3.31960000	7.26890000	0.07000
458	0.33230000	3.24820000	7.11240000	0.07000
459	0.64010000	3.16010000	6.91960000	0.07000
460	0.91850000	3.05670000	6.69310000	0.07000
461	1.16300000	2.93950000	6.43660000	0.07000
462	1.37000000	2.81030000	6.15370000	0.07000
463	0.00000000	3.11070000	7.36070000	0.07000

464	0.33230000	3.04380000	7.20230000	0.07000
465	0.64010000	2.96120000	7.00700000	0.07000
466	0.91850000	2.86430000	6.77760000	0.07000
467	1.16300000	2.75450000	6.51790000	0.07000
468	1.37000000	2.63340000	6.23140000	0.07000
469	0.00000000	2.89920000	7.44650000	0.07000
470	0.33230000	2.83680000	7.28630000	0.07000
471	0.64010000	2.75990000	7.08870000	0.07000
472	0.91850000	2.66960000	6.85670000	0.07000
473	1.16300000	2.56720000	6.59380000	0.07000
474	1.37000000	2.45440000	6.30410000	0.07000
475	0.00000000	2.68540000	7.52620000	0.07000
476	0.33230000	2.62760000	7.36430000	0.07000
477	0.64010000	2.55640000	7.16460000	0.07000
478	0.91850000	2.47260000	6.93010000	0.07000
479	1.16300000	2.37790000	6.66450000	0.07000
480	1.37000000	2.27340000	6.37160000	0.07000
481	0.00000000	2.46940000	7.59990000	0.11100
482	0.33230000	2.41620000	7.43630000	0.11100
483	0.64010000	2.35070000	7.23460000	0.11100
484	0.91850000	2.27370000	6.99790000	0.11100
485	1.16300000	2.18660000	6.72960000	0.11100
486	1.37000000	2.09050000	6.43390000	0.11100
487	0.00000000	2.25130000	7.66740000	0.15100
488	0.33230000	2.20290000	7.50230000	0.15100
489	0.64010000	2.14310000	7.29890000	0.15100
490	0.91850000	2.07300000	7.05990000	0.15100
491	1.16300000	1.99350000	6.78940000	0.15100
492	1.37000000	1.90600000	6.49100000	0.15100
493	0.00000000	2.03140000	7.72850000	0.11100
494	0.33230000	1.98780000	7.56220000	0.11100
495	0.64010000	1.93390000	7.35710000	0.11100
496	0.91850000	1.87050000	7.11630000	0.11100
497	1.16300000	1.79880000	6.84350000	0.11100
498	1.37000000	1.71980000	6.54280000	0.11100
499	0.00000000	1.81000000	7.78340000	0.07000
500	0.33230000	1.77100000	7.61580000	0.07000
501	0.64010000	1.72300000	7.40930000	0.07000
502	0.91850000	1.66660000	7.16670000	0.07000
503	1.16300000	1.60270000	6.89210000	0.07000
504	1.37000000	1.53220000	6.58920000	0.07000
505	0.00000000	1.58690000	7.83190000	0.07000
506	0.33230000	1.55280000	7.66330000	0.07000
507	0.64010000	1.51070000	7.45550000	0.07000
508	0.91850000	1.46130000	7.21140000	0.07000
509	1.16300000	1.40530000	6.93500000	0.07000

510	1.37000000	1.34350000	6.63020000	0.07000
511	0.00000000	1.36270000	7.87400000	0.07000
512	0.33230000	1.33330000	7.70450000	0.07000
513	0.64010000	1.29720000	7.49560000	0.07000
514	0.91850000	1.25470000	7.25020000	0.07000
515	1.16300000	1.20660000	6.97230000	0.07000
516	1.37000000	1.15360000	6.66590000	0.07000
517	0.00000000	1.13720000	7.90970000	0.07000
518	0.33230000	1.11270000	7.73940000	0.07000
519	0.64010000	1.08260000	7.52960000	0.07000
520	0.91850000	1.04710000	7.28310000	0.07000
521	1.16300000	1.00700000	7.00400000	0.07000
522	1.37000000	0.96276000	6.69610000	0.07000
523	0.00000000	0.91093000	7.93890000	0.07000
524	0.33230000	0.89133000	7.76800000	0.07000
525	0.64010000	0.86713000	7.55740000	0.07000
526	0.91850000	0.83873000	7.31000000	0.07000
527	1.16300000	0.80664000	7.02990000	0.07000
528	1.37000000	0.77121000	6.72090000	0.07000
529	0.00000000	0.68386000	7.96170000	0.07000
530	0.33230000	0.66913000	7.79040000	0.07000
531	0.64010000	0.65097000	7.57910000	0.07000
532	0.91850000	0.62968000	7.33110000	0.07000
533	1.16300000	0.60554000	7.05000000	0.07000
534	1.37000000	0.57892000	6.74020000	0.07000
535	0.00000000	0.45619000	7.97790000	0.07000
536	0.33230000	0.44639000	7.80630000	0.07000
537	0.64010000	0.43430000	7.59460000	0.07000
538	0.91850000	0.42007000	7.34610000	0.07000
539	1.16300000	0.40397000	7.06440000	0.07000
540	1.37000000	0.38623000	6.75400000	0.07000
541	0.00000000	0.22819000	7.98770000	0.11100
542	0.33230000	0.22327000	7.81580000	0.11100
543	0.64010000	0.21726000	7.60390000	0.11100
544	0.91850000	0.21016000	7.35500000	0.11100
545	1.16300000	0.20205000	7.07310000	0.11100
546	1.37000000	0.19314000	6.76230000	0.11100
547	0.00000000	0.00001495	7.99100000	0.15100
548	0.33230000	0.00004901	7.81900000	0.15100
549	0.64010000	-0.00001551	7.60700000	0.15100
550	0.91850000	0.00004126	7.35800000	0.15100
551	1.16300000	0.00000483	7.07600000	0.15100
552	1.37000000	0.00001577	6.76490000	0.15100
553	0.00000000	-0.22820000	7.98780000	0.11100
554	0.33230000	-0.22328000	7.81580000	0.11100
555	0.64010000	-0.21724000	7.60390000	0.11100

556	0.91850000	-0.21009000	7.35500000	0.11100
557	1.16300000	-0.20203000	7.07310000	0.11100
558	1.37000000	-0.19321000	6.76220000	0.11100
559	0.00000000	-0.45618000	7.97800000	0.07000
560	0.33230000	-0.44634000	7.80630000	0.07000
561	0.64010000	-0.43426000	7.59460000	0.07000
562	0.91850000	-0.42007000	7.34600000	0.07000
563	1.16300000	-0.40398000	7.06440000	0.07000
564	1.37000000	-0.38621000	6.75390000	0.07000
565	0.00000000	-0.68384000	7.96170000	0.07000
566	0.33230000	-0.66909000	7.79030000	0.07000
567	0.64010000	-0.65095000	7.57910000	0.07000
568	0.91850000	-0.62964000	7.33100000	0.07000
569	1.16300000	-0.60549000	7.05010000	0.07000
570	1.37000000	-0.57888000	6.74020000	0.07000
571	0.00000000	-0.91084000	7.93890000	0.07000
572	0.33230000	-0.89130000	7.76810000	0.07000
573	0.64010000	-0.86716000	7.55740000	0.07000
574	0.91850000	-0.83870000	7.31000000	0.07000
575	1.16300000	-0.80657000	7.02980000	0.07000
576	1.37000000	-0.77110000	6.72090000	0.07000
577	0.00000000	-1.13720000	7.90970000	0.07000
578	0.33230000	-1.11280000	7.73950000	0.07000
579	0.64010000	-1.08250000	7.52960000	0.07000
580	0.91850000	-1.04710000	7.28310000	0.07000
581	1.16300000	-1.00700000	7.00400000	0.07000
582	1.37000000	-0.96279000	6.69610000	0.07000
583	0.00000000	-1.36270000	7.87400000	0.07000
584	0.33230000	-1.33330000	7.70450000	0.07000
585	0.64010000	-1.29710000	7.49550000	0.07000
586	0.91850000	-1.25460000	7.25030000	0.07000
587	1.16300000	-1.20660000	6.97230000	0.07000
588	1.37000000	-1.15360000	6.66590000	0.07000
589	0.00000000	-1.58690000	7.83180000	0.07000
590	0.33230000	-1.55280000	7.66330000	0.07000
591	0.64010000	-1.51070000	7.45550000	0.07000
592	0.91850000	-1.46120000	7.21140000	0.07000
593	1.16300000	-1.40520000	6.93510000	0.07000
594	1.37000000	-1.34340000	6.63030000	0.07000
595	0.00000000	-1.81000000	7.78330000	0.07000
596	0.33230000	-1.77100000	7.61580000	0.07000
597	0.64010000	-1.72300000	7.40930000	0.07000
598	0.91850000	-1.66660000	7.16680000	0.07000
599	1.16300000	-1.60270000	6.89210000	0.07000
600	1.37000000	-1.53230000	6.58920000	0.07000
601	0.00000000	-2.03140000	7.72850000	0.11100

602	0.33230000	-1.98780000	7.56220000	0.11100
603	0.64010000	-1.93380000	7.35710000	0.11100
604	0.91850000	-1.87060000	7.11630000	0.11100
605	1.16300000	-1.79880000	6.84360000	0.11100
606	1.37000000	-1.71970000	6.54280000	0.11100
607	0.00000000	-2.25130000	7.66730000	0.15100
608	0.33230000	-2.20290000	7.50230000	0.15100
609	0.64010000	-2.14310000	7.29890000	0.15100
610	0.91850000	-2.07300000	7.06000000	0.15100
611	1.16300000	-1.99350000	6.78940000	0.15100
612	1.37000000	-1.90590000	6.49100000	0.15100
613	0.00000000	-2.46930000	7.59990000	0.11100
614	0.33230000	-2.41620000	7.43630000	0.11100
615	0.64010000	-2.35070000	7.23470000	0.11100
616	0.91850000	-2.27370000	6.99790000	0.11100
617	1.16300000	-2.18660000	6.72970000	0.11100
618	1.37000000	-2.09050000	6.43390000	0.11100
619	0.00000000	-2.68530000	7.52630000	0.07000
620	0.33230000	-2.62750000	7.36430000	0.07000
621	0.64010000	-2.55630000	7.16460000	0.07000
622	0.91850000	-2.47270000	6.93010000	0.07000
623	1.16300000	-2.37790000	6.66450000	0.07000
624	1.37000000	-2.27340000	6.37160000	0.07000
625	0.00000000	-2.89920000	7.44660000	0.07000
626	0.33230000	-2.83680000	7.28630000	0.07000
627	0.64010000	-2.75990000	7.08870000	0.07000
628	0.91850000	-2.66950000	6.85670000	0.07000
629	1.16300000	-2.56720000	6.59390000	0.07000
630	1.37000000	-2.45440000	6.30410000	0.07000
631	0.00000000	-3.11060000	7.36070000	0.07000
632	0.33230000	-3.04370000	7.20230000	0.07000
633	0.64010000	-2.96120000	7.00700000	0.07000
634	0.91850000	-2.86430000	6.77760000	0.07000
635	1.16300000	-2.75450000	6.51790000	0.07000
636	1.37000000	-2.63340000	6.23140000	0.07000
637	0.00000000	-3.31960000	7.26890000	0.07000
638	0.33230000	-3.24810000	7.11250000	0.07000
639	0.64010000	-3.16010000	6.91960000	0.07000
640	0.91850000	-3.05660000	6.69300000	0.07000
641	1.16300000	-2.93950000	6.43660000	0.07000
642	1.37000000	-2.81030000	6.15370000	0.07000
643	0.00000000	-3.52580000	7.17120000	0.07000
644	0.33230000	-3.44990000	7.01670000	0.07000
645	0.64010000	-3.35640000	6.82650000	0.07000
646	0.91850000	-3.24650000	6.60310000	0.07000
647	1.16300000	-3.12210000	6.34990000	0.07000

648	1.37000000	-2.98480000	6.07090000	0.07000
649	0.00000000	-3.72910000	7.06750000	0.07000
650	0.33230000	-3.64880000	6.91540000	0.07000
651	0.64010000	-3.54990000	6.72790000	0.07000
652	0.91850000	-3.43370000	6.50770000	0.07000
653	1.16300000	-3.30210000	6.25830000	0.07000
654	1.37000000	-3.15700000	5.98320000	0.07000
655	0.00000000	-3.92940000	6.95810000	0.07000
656	0.33230000	-3.84490000	6.80840000	0.07000
657	0.64010000	-3.74060000	6.62380000	0.07000
658	0.91850000	-3.61820000	6.40690000	0.07000
659	1.16300000	-3.47950000	6.16140000	0.07000
660	1.37000000	-3.32660000	5.89070000	0.07000
661	0.00000000	-4.12660000	6.84310000	0.11100
662	0.33230000	-4.03770000	6.69580000	0.11100
663	0.64010000	-3.92820000	6.51430000	0.11100
664	0.91850000	-3.79960000	6.30100000	0.11100
665	1.16300000	-3.65410000	6.05950000	0.11100
666	1.37000000	-3.49340000	5.79320000	0.11100
667	0.00000000	-4.32030000	6.72250000	0.15100
668	0.33230000	-4.22720000	6.57780000	0.15100
669	0.64010000	-4.11270000	6.39950000	0.15100
670	0.91850000	-3.97800000	6.19000000	0.15100
671	1.16300000	-3.82560000	5.95270000	0.15100
672	1.37000000	-3.65740000	5.69110000	0.15100
673	0.00000000	-4.51040000	6.59630000	0.11100
674	0.33230000	-4.41330000	6.45430000	0.11100
675	0.64010000	-4.29370000	6.27940000	0.11100
676	0.91850000	-4.15310000	6.07380000	0.11100
677	1.16300000	-3.99400000	5.84110000	0.11100
678	1.37000000	-3.81840000	5.58430000	0.11100
679	0.00000000	-4.69700000	6.46490000	0.07000
680	0.33230000	-4.59590000	6.32570000	0.07000
681	0.64010000	-4.47130000	6.15420000	0.07000
682	0.91850000	-4.32490000	5.95270000	0.07000
683	1.16300000	-4.15910000	5.72460000	0.07000
684	1.37000000	-3.97640000	5.47300000	0.07000
685	0.00000000	-4.87970000	6.32810000	0.07000
686	0.33230000	-4.77460000	6.19190000	0.07000
687	0.64010000	-4.64520000	6.02400000	0.07000
688	0.91850000	-4.49310000	5.82680000	0.07000
689	1.16300000	-4.32100000	5.60350000	0.07000
690	1.37000000	-4.13100000	5.35730000	0.07000
691	0.00000000	-5.05840000	6.18610000	0.07000
692	0.33230000	-4.94950000	6.05300000	0.07000
693	0.64010000	-4.81530000	5.88890000	0.07000

694	0.91850000	-4.65770000	5.69610000	0.07000
695	1.16300000	-4.47920000	5.47780000	0.07000
696	1.37000000	-4.28230000	5.23700000	0.07000
697	0.00000000	-5.23300000	6.03920000	0.07000
698	0.33230000	-5.12030000	5.90920000	0.07000
699	0.64010000	-4.98150000	5.74900000	0.07000
700	0.91850000	-4.81850000	5.56080000	0.07000
701	1.16300000	-4.63380000	5.34770000	0.07000
702	1.37000000	-4.43010000	5.11270000	0.07000
703	0.00000000	-5.40330000	5.88730000	0.07000
704	0.33230000	-5.28700000	5.76060000	0.07000
705	0.64010000	-5.14370000	5.60440000	0.07000
706	0.91850000	-4.97530000	5.42100000	0.07000
707	1.16300000	-4.78460000	5.21320000	0.07000
708	1.37000000	-4.57430000	4.98400000	0.07000
709	0.00000000	-5.56920000	5.73060000	0.07000
710	0.33230000	-5.44930000	5.60720000	0.07000
711	0.64010000	-5.30160000	5.45520000	0.07000
712	0.91850000	-5.12810000	5.27670000	0.07000
713	1.16300000	-4.93150000	5.07450000	0.07000
714	1.37000000	-4.71480000	4.85140000	0.07000
715	0.00000000	-5.73060000	5.56920000	0.07000
716	0.33230000	-5.60720000	5.44940000	0.07000
717	0.64010000	-5.45520000	5.30160000	0.07000
718	0.91850000	-5.27660000	5.12810000	0.07000
719	1.16300000	-5.07440000	4.93150000	0.07000
720	1.37000000	-4.85140000	4.71480000	0.07000
721	0.00000000	-5.88730000	5.40330000	0.11100
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728	0.33230000	-5.90920000	5.12030000	0.15100
729	0.64010000	-5.74900000	4.98150000	0.15100
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735	0.53260000	0.00000007	7.40200000	0.125000
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740	0.21440000	-0.00001236	7.27100000	0.125000
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757	0.00000000	-4.14830000	6.45500000	0.125000
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831	0.62400000	-2.23550000	7.61350000	0.125000

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833	1.26000000	-2.04170000	6.95340000	0.125000
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855	0.62400000	-5.99690000	5.19630000	0.125000
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*ELEMENTS 75
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C ************************************************
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 18 103 109 110 104
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C
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  610    838
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  612    840
C
  667    847
  668    848
  669    849
  670    850
  671    851
  672    852
C
  727    859
  728    860
  729    861
  730    862
  731    863
  732    864
C END OF DUPLICATED NODES

*PROPERTIES 75
C
C  E     = 25.5E+6  Modulus of Elasticity
C  PR    = 0.33     Poison's Ratio
C  ALPHA = 0.0      Coefficient of thermal expension
C  DEN   = 0.305    WEIGHT/VOLUME = 7.89337474E-4 MASS/VOLUME
C
 1 942  0.0 25.5E+6  0.33  0.0 7.89337474E-4
*ITER 0 11
 50
*DAMPING 2
  1  50 0.005
```

*PSD 1
C pai= 3.1415927410126

0.31415927E+02	0.12300051E-12
0.15854236E+03	0.90517143E-10
0.28566880E+03	0.52999231E-09
0.41279523E+03	0.80679458E-09
0.53992167E+03	0.10094673E-08
0.66704810E+03	0.12478097E-08
0.79417580E+03	0.15437727E-08
0.92130349E+03	0.19053074E-08
0.10484249E+04	0.23390524E-08
0.11755526E+04	0.28523111E-08
0.13026803E+04	0.34536303E-08
0.14298080E+04	0.41527502E-08
0.15569357E+04	0.49608594E-08
0.16840571E+04	0.58905630E-08
0.18111848E+04	0.69560735E-08
0.19383125E+04	0.81732905E-08
0.20654401E+04	0.95599438E-08
0.21925616E+04	0.11135785E-07
0.23196892E+04	0.12922744E-07
0.24468169E+04	0.14945110E-07
0.25739446E+04	0.17229795E-07
0.27010723E+04	0.19806514E-07
0.28281937E+04	0.22708386E-07
0.29553214E+04	0.25971380E-07
0.30824491E+04	0.29635764E-07
0.32095768E+04	0.33745622E-07
0.33367045E+04	0.38349815E-07
0.34638259E+04	0.43501979E-07
0.35909536E+04	0.49261477E-07
0.37180813E+04	0.55693247E-07
0.38452090E+04	0.62869384E-07
0.39723367E+04	0.70868670E-07
0.40994581E+04	0.79778323E-07
0.42265858E+04	0.89693994E-07
0.43537135E+04	0.10072104E-06
0.44808412E+04	0.11297534E-06
0.46079689E+04	0.12658420E-06
0.47350903E+04	0.14168721E-06
0.48622180E+04	0.15843810E-06
0.49893456E+04	0.17700576E-06
0.51164733E+04	0.19757335E-06
0.52436010E+04	0.22034365E-06
0.53707224E+04	0.24553946E-06
0.54978501E+04	0.27339954E-06

0.56249778E+04	0.30418965E-06
0.57521055E+04	0.33819629E-06
0.58792332E+04	0.37573298E-06
0.60063546E+04	0.41713873E-06
0.61334823E+04	0.46277800E-06
0.62606100E+04	0.51305027E-06
0.63877377E+04	0.56838048E-06
0.65148465E+04	0.62922701E-06
0.66420182E+04	0.69607845E-06
0.67691270E+04	0.76945365E-06
0.68962359E+04	0.84990170E-06
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0.72776252E+04	0.11395828E-05
0.74047341E+04	0.12543271E-05
0.75318429E+04	0.13792335E-05
0.76590146E+04	0.15149497E-05
0.77861234E+04	0.16621028E-05
0.79132323E+04	0.18213214E-05
0.80404040E+04	0.19931610E-05
0.81675128E+04	0.21781467E-05
0.82946217E+04	0.23767084E-05
0.84217305E+04	0.25892121E-05
0.85489022E+04	0.28158647E-05
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0.11345674E+05	0.99761180E-05

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0.81675128E+04	0.88461021E-05

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13. ABSTRACT ***(Maximum 200 words)***

This report describes a probabilistic structural analysis performed to determine the probabilistic structural response under fluctuating random pressure loads for the Space Shuttle Main Engine (SSME) turnaround vane. It uses a newly developed frequency and distance dependent correlation model that has features to model the decay phenomena along the flow and across the flow with the capability to introduce a phase delay. The analytical results are compared using two computer codes SAFER (Spectral Analysis of Finite Element Responses) and NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) and with experimentally observed strain gage data. The computer code NESSUS with an interface to a sub set of Composite Load Spectra (CLS) code is used for the probabilistic analysis. A Fatigue code was used to calculate fatigue damage due to the random pressure excitation. The random variables modeled include engine system primitive variables that influence the operating conditions, convection velocity coefficient, stress concentration factor, structural damping, and thickness of the inner and outer vanes. The need for an appropriate correlation model in addition to magnitude of the PSD is emphasized. The study demonstrates that correlation characteristics even under random pressure loads are capable of causing resonance like effects for some modes. The study identifies the important variables that contribute to structural alternate stress response and drive the fatigue damage for the new design. Since the alternate stress for the new redesign is less than the endurance limit for the material, the damage due high cycle fatigue is negligible.

14. SUBJECT TERMS
Random vibrations; Fluctuating loads; Phase delay; Fatigue damage; Thermostructural; Primitive variables; Stress concentration; Structural damping; Distant correlations; High-cycle fatigue

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